

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

**THE WEATHERING OF PLACER GOLD AND THE
QUATERNARY GEOLOGY OF VALDEZ CREEK,
CLEARWATER MOUNTAINS, ALASKA**

A

THESIS

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Steven D. Teller, B.S.

Fairbanks, Alaska

May 1995

UMI Number: 1376242

UMI Microform 1376242

Copyright 1995, by UMI Company. All rights reserved.

**This microform edition is protected against unauthorized
copying under Title 17, United States Code.**

UMI

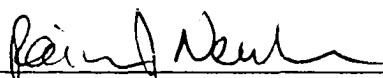
**300 North Zeeb Road
Ann Arbor, MI 48103**

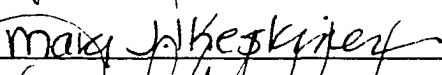
**THE WEATHERING OF PLACER GOLD AND THE
QUATERNARY GEOLOGY OF VALDEZ CREEK,
CLEARWATER MOUNTAINS, ALASKA**

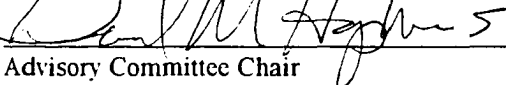
By

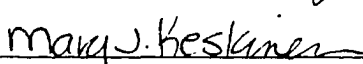
Steven D. Teller

RECOMMENDED:






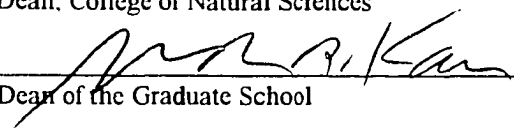



Advisory Committee Chair


Department Head

APPROVED:



Dean, College of Natural Sciences


Dean of the Graduate School


Date

ABSTRACT

Placer gold grains collected from six paleochannels in the Valdez Creek drainage, south-central Alaska, were deposited during successive interglacial/interstadial intervals since the mid-Early Pleistocene. Statistical analysis of grain size, shape, grain surface characteristics, and the gold content of the interior and exterior of the gold grains determined by electron microprobe analysis demonstrates that the grains were affected by both mechanical and chemical weathering, and that the weathering increased with time. Etch pits, observed under a scanning electron microscope, are a ubiquitous feature of the grain surfaces. Grain surfaces average 26.7% richer in gold than the interior of the grains. The gold content of the surface of the grains increases with age. No high gold fineness rims were observed in cross section on the grains. This evidence indicates that the gold grains experienced corrosion.

TABLE OF CONTENTS

ABSTRACT.....	iii
TABLE OF CONTENTS	iv
SHEET.....	viii
FIGURES.....	viii
TABLES.....	xi
ACKNOWLEDGMENTS.....	xii
1. INTRODUCTION	1
2. PREVIOUS WORK	3
2.1. GEOCHEMISTRY OF GOLD IN THE SURFICIAL ENVIRONMENT	3
2.2. STUDIES OF TRACE ELEMENT ZONING IN NATURAL GOLD PARTICLES	5
3. LOCATION AND ACCESS	6
4. PHYSIOGRAPHY	8
5. CLIMATE AND VEGETATION	11
6. HISTORY	13
6.1. DISCOVERY.....	13
6.2. EARLY DAYS.....	15
6.3. OTHER AREAS	15
6.4. RECENT HISTORY	16
7. BEDROCK GEOLOGY	18
7.1. STRATIGRAPHY	18
7.1.1. AMPHITHEATER GROUP.....	18
7.1.2. MACLAREN METAMORPHIC BELT	18
7.1.3. INTRUSIVE ROCKS	20
7.2. STRUCTURE	21
7.3. TECTONIC INTERPRETATION.....	21
8. LATE CENOZOIC GEOLOGY.....	23
8.1. INTRODUCTION.....	23

8.2. SURFICIAL GEOLOGY	23
8.2.1. HIGH LEVEL SURFACE.....	23
8.2.2. PRE-WISCONSINAN GLACIAL DEPOSITS.....	26
8.2.3. LATE WISCONSINAN GLACIAL DEPOSITS	27
8.2.4. HOLOCENE GLACIAL AND ALLUVIAL DEPOSITS.....	28
8.3. THE PALEOCHANNELS AND THEIR DEPOSITS.....	29
8.3.1. DESCRIPTION OF CHANNELS	29
8.3.2. GENERALIZED STRATIGRAPHY AS OBSERVED IN THE A CHANNEL.....	32
8.3.3. INTERPRETATION PROBLEMS	34
8.4. ORIGIN OF THE CHANNELS	35
8.4.1. CHRONOLOGY OF CHANNELS	39
8.4.2. OTHER AREAS	42
9. EXPERIMENTAL DESIGN.....	43
9.1. INTRODUCTION.....	43
9.2. DESIGN	43
9.3. SAMPLING	43
10. DRILL STUDY.....	46
10.1. INTRODUCTION.....	46
10.2. BACKGROUND.....	47
10.3. EXPERIMENTAL DESIGN	48
10.4. HAND SAMPLES	49
10.5. DRILL SAMPLES	50
10.6. COMPARISON OF DRILL AND GRAB/CHANNEL SAMPLES	57
10.7. DISCUSSION.....	63
10.8. SUMMARY	64
11. GRAIN SIZE	65
11.1. INTRODUCTION.....	65
11.2. MEASUREMENT	65
11.3. BASIC STATISTICS.....	65
11.4. RESULTS AND DISCUSSION.....	66

12. GRAIN SHAPE	70
12.1. INTRODUCTION.....	70
12.2. RESULTS	71
12.3. DISCUSSION	72
13. GOLD GRAIN SURFACE MORPHOLOGY.....	76
13.1. INTRODUCTION.....	76
13.2. INHERITED	76
13.3. OVERGROWTHS	77
13.4. MECHANICAL DEFORMATION	77
13.5. CORROSION.....	77
13.5.1. INTRODUCTION	77
13.5.2. FINE PITTING	81
13.5.2.1. Absolute Pit Size	82
13.5.2.2. Size Distribution at 400x Magnification.....	82
13.5.2.3. Total Pit Area.....	84
13.5.2.4. Density of Pitting.....	84
13.5.2.5. Fine Pitting Summary	86
13.5.3. LARGE SCALE PITTING.....	86
14. GOLD FINENESS.....	88
14.1. INTRODUCTION.....	88
14.2. GRAIN INTERIOR.....	89
14.3. GRAIN SURFACE	95
14.4. DISCUSSION	100
15. MULTIVARIATE STATISTICAL ANALYSIS	106
15.1. INTRODUCTION.....	106
15.2. CORRELATIONS.....	106
15.3. DISCRIMINANT ANALYSES	109
15.4. CLUSTER ANALYSIS	115
16. DISCUSSION AND CONCLUSIONS.....	120
16.1. CHEMICAL WEATHERING OF GOLD GRAINS.....	121

16.2. RELATIVE AGE OF CHANNELS	124
16.3. TIME-STRATIGRAPHIC INTERPRETATION	125
16.4. INFERENCES ABOUT THE LODE SOURCE	128
16.5. FURTHER WORK	129
17. REFERENCES	131
18. APPENDICES	139
18.1. APPENDIX 1. RAW DATA FOR DRILLING STUDY (CHAPTER 10), +20 MESH GOLD GRAINS	140
18.2. APPENDIX 2. RAW DATA, +20 MESH GOLD GRAINS.	144

SHEET

Quaternary Geology of the Valdez Creek area(in pocket)

FIGURES

Figure 3-1 Location Map (state)	7
Figure 4-1 Regional Location Map	10
Figure 6-1 Location Map - Valdez Creek Drainage.....	14
Figure 7-1 Bedrock geology, Valdéz Creek area.	19
Figure 8-1 Map of Valdez Creek paleochannels and location of samples used in this study.....	31
Figure 8-2 Approximate late Wisconsinan glacial limits, Valdez Creek area.	37
Figure 10-1 Drill study sample locations.	51
Figure 10-2 Log-probability plot of grain weight for gold grains collected by hand.....	53
Figure 10-3 Probability plot of CSF of gold grains collected by hand.....	53
Figure 10-4 Corey shape factor relative to log weight for grains collected by hand.....	54
Figure 10-5 Log -probability plot of grain weight for gold grains collected by drilling.	56
Figure 10-6 Probability plot of CSF of gold grains collected by drilling.....	56
Figure 10-7 Corey shape factor relative to log weight for grains from drill samples.	57
Figure 10-8 Box plots comparing CSF of grains collected by hand and by drilling.....	59
Figure 10-9 Box plots comparing log weight distribution of grains collected by hand and by drilling.....	59
Figure 10-10 Semi-log plot comparing gold grains collected by hand and by drilling--entire population. 50% of the given population will fall within the ellipse.....	60
Figure 10-11 Semi-log plot comparing gold grains collected by hand and by drilling--Area 1.....	61
Figure 10-12 Semi-log plot comparing gold grains collected by hand and by drilling--Area 4.....	62
Figure 10-13 Semi-log plot comparing gold grains collected by hand and by drilling--Area 2.....	62
Figure 11-1 Scatter plot matrix of weight, length, width, thickness, and Corey shape factor (CSF). Data are standard normal; 50% of the populations should fall within the ellipses assuming they are bivariate normal. Narrow ellipses indicate high correlation between variables; more circular ellipses indicate poor correlation.....	68
Figure 11-2 Box plots showing distribution of weight, length, width, and thickness by channel--VCM only. Data are standard normal.	69
Figure 12-1 Probability plots of CSF, sphericity, and regularity. Data are standard normal.....	73

Figure 12-2 Scatter plot matrix showing correlation of CSF, sphericity, and regularity (standard-normal data).....	74
Figure 12-3 Box plots by channel of CSF, sphericity, and regularity. Data are standard normal.....	75
Figure 13-1 Photomicrograph of placer gold grain showing modified crystal growth steps and etch pits. Grain is from the A Channel, 400x magnification, bar-scale is 100 μm long.....	78
Figure 13-2 Photograph of placer gold grain showing rolled edges, scratches, and "macro" pits which give a frosted appearance (see text for explanation). Grain is 3.0 mm x 2.4 mm and 0.7 mm thick .	78
Figure 13-3 Photomicrograph of placer gold grain showing areas with chemical weathering (rough pitted area) and mechanical weathering (smooth area at right center). Smooth striated area possibly formed during glacial transport. Grain is from the A Bench, 390x magnification, bar-scale is 100 μm long.....	79
Figure 13-4 Photograph of Valdez Creek Mine coarse gold cleanup. The gold is typically flat and regular in shape.....	79
Figure 13-5 Photomicrograph of highly modified placer gold grain showing high density of pitting and almost obscured crystal growth steps. Grain is from the A Bench, 400x magnification, bar-scale is 100 μm long.....	80
Figure 13-6 Photomicrograph with enlargement of smooth striated area of Figure 13-3 showing development of small etch pits (1500x magnification, bar-scale is 10 μm long).	80
Figure 13-7 Log-probability plot of pit size from typical grain.....	83
Figure 13-8 Box plots of pit size at 400x for eight grains with duplicate analyses. Data are standard normal.....	85
Figure 13-9 Box plot of large scale pitting grouped by channel. Data are standard normal.....	87
Figure 14-1 Box plots of individual grain interior gold content. Data are untransformed.	90
Figure 14-2 Probability plot of the mean gold content of the interior of the gold grains. Data are standard normal.....	93
Figure 14-3 Box plots of grain interior gold content by channel. The thresholds for the three subpopulations are also plotted. Asterisks show outliers, circles show extreme outliers. Data are untransformed.	94
Figure 14-4 Probability plot of grain surface gold content (untransformed data).	97
Figure 14-5 Probability plot of grain surface gold content (standardized and normalized).....	97
Figure 14-6 Scatter plot matrix of grain surface (sfine) and interior (ifine) gold content, and change (delta) in gold content between surface and interior (standard-normal data).....	98

Figure 14-7 Box plots of change in gold content between surface and interior of grain by channel (standard-normal data).	99
Figure 14-8 Box plots of grain surface gold content by channel (standard-normal data).	99
Figure 14-9 Au, Ag, Cu, and Hg contents of the cross section Grain 81 from the Tammany Channel (untransformed data, lines fitted using distance weighted least squares smoothing [SYSTAT, 1992]).....	102
Figure 14-10 Au, Ag, Cu, and Hg content of the cross section of Grain 7 from White Creek (untransformed data, lines fitted using distance weighted least squares smoothing [SYSTAT, 1992]).....	103
Figure 15-1 Scatter plot matrix of seven variables that are valid throughout the study area.	108
Figure 15-2 Plot of first two factors from first discriminant analysis. Analysis on all valid variables (SFINE, IFINE, DELTA, REG, SPH, CSF, PITTING) that describe grains from all six channels. Varimax rotation on 2 factors.	110
Figure 15-3 Plot of first two factors from second discriminant analysis. Analysis on selected variables (SFINE, CSF, REG, PITTING) describing grains from all six channels. Varimax rotation on 2 factors.....	112
Figure 15-4 Plot of first two factors from third discriminant analysis. Analysis on selected variables (SFINE, CSF, REG, PITTING, WT, TH, LG, WT, SPHERE) describing grains from the four Valdez Creek Mine channels only. Varimax rotation on 2 factors.	114
Figure 15-5 Discriminant analysis plot of Clusters using IFINE, SFINE, DELTA, SPHERE, REG, PITTING, and CSF from grains from the entire study area.	117

TABLES

Table 5-1 Average yearly temperature and precipitation for selected Alaskan stations.	11
Table 6-1 Valdez Creek gold production.....	17
Table 8-1 Valdez Creek age dates.....	40
Table 10-1 Basic statistics for +20 mesh gold grains collected by hand.....	52
Table 10-2 Basic statistics for +20 mesh gold grains from drill samples.	55
Table 10-3 Drilling recovery ANOVA results.....	57
Table 10-4 Weight difference between +20 mesh gold grains collected by hand and by drilling.	60
Table 10-5 Comparison of the subareas using F and t statistics.....	61
Table 11-1 Basics statistics for the size variables--VCM only.	67
Table 12-1 Basic statistics for CSF, sphericity, and regularity.....	74
Table 13-1 Approximate size (surface area) of corrosion pits in gold grains in the Valdez Creek drainage adjusted for truncation using Probplot (Stanley, 1987).	83
Table 13-2 Nested ANOVA of pit size at 400x magnification.	85
Table 14-1 Nested analysis of variance of duplicate analyses of grain interior gold content. Duplicate test consisting of 2 sets of 10 analyses each for 10 grains.	93
Table 14-2 Basic statistics for the interior gold content of the entire sample population of gold grains and for three subpopulations.....	94
Table 14-3 Basic statistics for grain fineness (interior, surface, and change).	98
Table 14-4 Summary of ANOVA results for grain gold contents by channel.	100
Table 14-5 Oxidation potential of selected half-reactions at 25°C and 1 atmosphere pressure.	104
Table 15-1 Pearson correlation matrix for the seven statistically valid variables.....	107
Table 15-2 Rotated canonical loadings on first 2 factors from first discriminant analysis (seven variables and all six channels).	109
Table 15-3 Rotated canonical loadings on first 2 factors from second discriminant analysis (four variables and all six channels).	111
Table 15-4 Rotated canonical loadings on first 2 factors from third discriminant analysis (nine dependent variables and the four Valdez Creek Mine channels only).	113
Table 15-5 Rotated canonical loadings on first 3 factors from discriminant analysis that uses the five Clusters as the grouping/categorical variable (seven dependent variables and 40 grains from all six channels).....	118

ACKNOWLEDGMENTS

First, I would like to thank the U.S. Bureau of Mines, Anchorage Field Office. This project could not have happened without their initial funding as part of their Valdez Mining District Project. In particular, I would like to thank Joe Kurtak and Bob Hoekzema of that office for their support. Valuable assistance in SEM and image analysis was provided by Keith Collins, Arnold Adams, and Jim Watson of the U.S. Bureau of Mines Research Center in Albany, Oregon.

The staff and management of Valdez Creek Mining Co. (now Cambior Alaska) have been very supportive throughout the project. My thanks go to Jerry O'Connor, Paul Martin, Jim Prudden, and the many other current and former employees who shared their ideas and time.

This project would not have been possible without the strong foundation laid by Jason Bressler of WGM, Anchorage, who did the geology that led to the real understanding of the deposit. Thank you, Jason, for your good work, support, and for letting a student come in so close on your heels.

I would like to thank Dave Hopkins, University of Alaska Fairbanks (UAF), Department of Geology and Geophysics, and Tom Bundtzen, Alaska Division of Geological and Geophysical Surveys, for the initial mine tour and discussions that exposed me to this unique deposit. I would also like to thank Dave Hopkins, Gail Ashley, UAF Visiting Professor from Rutgers University, and Tom Hamilton, U.S. Geological Survey, for their help in crystallizing my ideas about the genesis of the deposit.

I would like to thank Dave Hopkins, Rainer Newberry, and Dan Hawkins (retired) of the University of Alaska Fairbanks, Department of Geology and Geophysics, for their enthusiastic support throughout the study.

The quality of the final draft is due to the efforts of Leonard Nelson's CAD work and Lois Clifton's editorial assistance--thank you.

Finally, I would like to thank my wife, Susan Karl, for putting up with a graduate student, just when she thought she was finished with that life, and my parents, Henry and Ellen Teller, for the curiosity they gave me and the unqualified support that is always there.

1. INTRODUCTION

This is a study of the subsurface weathering of gold under subarctic conditions. The gold deposited in the Valdez Creek, Alaska gold placer has been chosen for this study because of the unique depositional history in which gold was deposited in a series of deeply buried paleochannels. These channels are the focus of a large scale open pit mining operation at the Valdez Creek Mine (formerly the Denali Mine).

The objective of this study is to determine the effect of long term, natural weathering on placer gold. (Placer gold is a mixture of gold, lesser silver, and traces of other metals. This compound is electrum, if greater than 20% silver; however, it is traditionally referred to simply as gold, the predominant metal. This tradition will be followed in this thesis.) Is the weathering strictly mechanical or is there post-depositional chemical weathering as well? Is the chemical weathering destructive (as is typical for most geologic material) or is it constructive (as has often been reported)? Does placer gold grow? Finally, does the weathering occur at a rate that allows it to be used as a relative dating tool?

The Valdez Creek placer deposit offers an ideal natural laboratory for this study. The placer gold is present in paleochannels incised into bedrock and buried beneath glaciofluvial sediment. Each paleochannel was formed during a different interglacial period. Thus, there are six populations of gold grains that are available, each from a different paleochannel, and each potentially representing a different period of time. The total time represented is thought to be from the Plio/Pleistocene boundary to mid-Wisconsin (1.65 ma to 23 ka).

Mechanical weathering is to be expected and is only incidentally analyzed. The primary focus is on chemical weathering. The underlying assumption for this study is that any chemical change to a gold grain is a function of the amount of time the grain has been in the surficial environment. Therefore, gold deposited in the oldest channel, having been in the surficial environment the longest, should be the most affected, while gold in the youngest deposit, which has entered the surficial environment relatively recently, will be the least affected.

The study has two parts. In the first part, the climate, physiography, bedrock geology, and surficial geology are examined to understand the nature of the deposit from which the gold grains were collected. Geologic evidence bearing on the ages of the paleochannels is examined. The second part of the study is a statistical analysis of several variables used to quantify the nature of the gold grains. These variables include traditional sedimentological characteristics, micro-surface features examined with a scanning electron microscope (SEM), surface gold fineness determined with the energy dispersive system (EDS) of the SEM, and interior gold fineness determined with an electron microprobe. Each variable is presented individually. Finally, the variables will be used in multivariate analyses, principal of which are discriminant analyses. The root of the discriminant analyses, using the channels as the grouping variable, should include the weathering factor(s) that are the focus of the study.

2. PREVIOUS WORK

2.1. GEOCHEMISTRY OF GOLD IN THE SURFICIAL ENVIRONMENT

Recent work on the geochemistry of gold has increased the understanding of its behavior in the surface environment. Krauskopf (1951, 1979) demonstrated that, in theory, gold may be oxidized in very acid solutions in the presence of a very strong oxidant, such as MnO_2 , and held in solution if it is immediately complexed by chloride. Lakin *et al.* (1974) found that two other halides, Br^- and I^- , will also form Au complexes. They showed that the ease of oxidation of gold is affected by the complexing agents present and that the stability of the Au complex formed is reflected in the ease of oxidation. Thus, the ease of oxidation and stability associated with the following complexing ions increase in the order of Cl^- , Br^- , CNS^- , I^- , and CN^- , with $\text{S}_2\text{O}_3^{2-}$ probably falling between CNS^- and I^- . Lakin *et al.* (1974) went on to suggest that gold cyanide is the most likely form of soluble Au in soils. There are over 1000 species of plants containing cyanogenetic substances. Gold leaf will dissolve in aqueous suspensions of macerated material from those plants that were tested by Lakin *et al.* (1974). Baker (1978) took the biogenic idea further and showed that significant quantities of Au can be dissolved, complexed, and transported by humic acid. This is significant in that humic acid is present in the environment from the very beginning of soil formation. Recently, Bowen (1985) stated that humates are able to dissolve Au in acid conditions. Most recently, Vlassopoulos and Wood (1990) have presented new thermodynamic data on the hydrolysis of gold. Using their results, they were able to redraw the pE-pH diagram for the Au-Cl- H_2O . This diagram demonstrates that, under conditions expected in supergene waters, $\text{AuOH}(\text{H}_2\text{O})^0$, rather than AuCl_4^- , is the predominant aqueous species. However, Benedetti and Boulègue (1991) showed that, in streams draining sulfide-bearing gold deposits, under otherwise typical supergene conditions, the concentration of thiosulfate may be high enough that gold is soluble as the gold thiosulfate complex $\text{Au}(\text{S}_2\text{O}_3)_2^{3-}$.

The ease of removal of gold from solution by sorption or reduction is a function of the stability of its complex ions (see above). Lakin *et al.* (1974) studied the removal of Au from solution in the presence of 114 minerals. They found that the halide complexes are much less

stable and that sulfide minerals are much more effective in removing Au from solution. Krendelev *et al.* (1978) found, using the radioactive isotope ^{195}Au , that gold removed from solution is found at crystal edges and crystal defects in layer silicates, rather than at cation exchange sites between layers. Watterson *et al.* (1983) have shown that gold will precipitate on spores of *Bacillus cereus* from concentrated AuCl_4^- solutions. Jean and Bancroft (1985) showed that Au is deposited from low temperature solutions onto the surface of sulfide minerals by reduction. Recently, Vlassopoulos *et al.* (1990) found that organic ligands may solubilize or fix Au depending on the conditions. For instance, humic acid is insoluble under acidic conditions and its presence will fix Au. Benedetti and Boulègue (1991) observed that oxidation of thiosulfate will result in the destabilization of the aurothiosulfate complex and that the gold is then reduced to submicron-sized metallic particles.

The majority of the work to date has been experimental or theoretical in nature. In a field oriented study, Lesure (1971) showed for a single sample that Au may be mobilized and deposited with limonite in the surficial environment. Lakin *et al.* (1974) showed that gold is sometimes concentrated in the organic soil horizon and suggested that this is due to plants taking up aqueous Au that is then deposited in the soil with the plant detritus. They also showed that Au may be concentrated in the lowest soil layer and suggested that this may be due to gravity separation (similar to alluvial Au concentration) during surficial slope processes. Mann (1984), studying laterites in western Australia, found good evidence that ferrolysis (oxidation and hydrolysis of iron) has dissolved and then precipitated Au from nuggets in contact with iron oxide. Benedetti and Boulègue's (1991) results concerning the aurothiosulfate complex (cited earlier) are based on aqueous geochemical stream sample results.

Is it possible that certain environments are more favorable for supergene movement of gold? Watterson (1985), in a significant review of the subject, suggests that periglacial regions may offer just such an environment. Part of the water in frozen soils persists in the liquid state to temperatures as low as -9°C . As water crystallizes, impurities are excluded from the solid phase. The immediate effect is an increased concentration of ions, and therefore, of gold complexing agents in the remaining unfrozen water. Carbonic acid, nitric acid, and organic acids may also be concentrated, leading to increased weathering of rock which would make more gold available. The exclusion process is somewhat more efficient for cations than anions, resulting in an electric

potential across the ice/water interface. Furthermore, because a frozen soil at a downward-migrating freezing front contains water with an excess of cations, it acts as an electron acceptor relative to neutral water in unfrozen soil. This process is sufficiently active to electrolytically oxidize buried pipelines. The trans-Alaskan pipeline required extensive cathode protection partly for this reason (Watterson, 1985). The major hurdle in the chemistry of gold is its extremely low redox potential. Freezing voltages as high as 120 volts have been observed for bentonite and saline solutions, but voltages on the order of 0.15 volts are more common. Freezing voltages are of the right sign and magnitude, and thus may be a very important factor in the supergene movement of gold.

2.2. STUDIES OF TRACE ELEMENT ZONING IN NATURAL GOLD PARTICLES

Gorshkov *et al.* (1971) traced a sequence of gold particles from the Khualazinsk lode deposit down the Tinkan River to beach placers on the Bay of Tinkan, Southern Maritime Province, Russia. In addition to finding a steady increase in fineness (Au concentration), they noted a decrease in Pb, Bi, Sb, and Te content while Cu remained the same and Hg increased slightly. They also found that the particles have a narrow rind of purer gold, which increases in thickness with increasing distance from the source. These changes were attributed to progressive leaching by Gorshkov *et al.* (1971), but other workers have cited these sorts of changes as evidence for precipitation of gold from solution. Using an electron microprobe, Groen *et al.* (1987) found high fineness rims on placer gold grains from the southeastern United States. He attributed these rims to precipitation of gold from solution.

Very limited work has been done on trace element zoning of gold in lode deposits. Microprobe work by Sakharova (1969), and Sakharova and Demidov (1972) shows that, in lode deposits, trace element content in gold grains is variable, but the Au/Ag ratio decreases toward the margin (opposite to the trend found in placer grains). This effect is said to be more pronounced in gold inclusions in sulfide grains and was not present in gold disseminated in quartz. In a review of the gold fineness of different types of lode gold deposits, Morrison *et al.* (1991) note that, in epithermal Au-Ag deposits, gold content is extremely variable from grain to grain and even within single grains, but in other deposit types, such as Archean, slate belt, and plutonic environments, the gold content is quite uniform within a deposit.

3. LOCATION AND ACCESS

Valdez Creek, a tributary to the Susitna River, is located 250 km (150 mi), by air, north of Anchorage, Alaska (Figure 3-1). By road, it can be reached from the Parks Highway at Cantwell by driving 92 km (57 mi) east on the Denali Highway (an all-weather gravel road) to just past the Susitna River bridge, and then turning north and driving an additional 8 km (5 mi) on a well maintained gravel road. Access has been year-round since mining began in earnest at the Valdez Creek Mine in the 1980's. Previously, the Denali Highway was not plowed in the winter.

The Valdez Creek Mine (formerly the Denali Mine) is located adjacent to Valdez Creek, 3 km (2 mi) from the confluence of Valdez Creek with the Susitna River. The Valdez Creek valley beyond the Valdez Creek Mine, and the majority of Valdez Creek's tributaries, are accessible by a dirt road that runs up the center of the valley, forks at White Creek, and ends at Roosevelt Lake. A vehicle with high clearance can traverse the road during most of the summer. Valdez Creek must be forded just below White Creek, which is a problem only during occasional high runoff periods in mid-summer. Most points within the drainage are easily reached on foot, thanks to relatively little brush and few bogs. Winter access in the valley is by snow machine, skis, or other over-the-snow transportation.

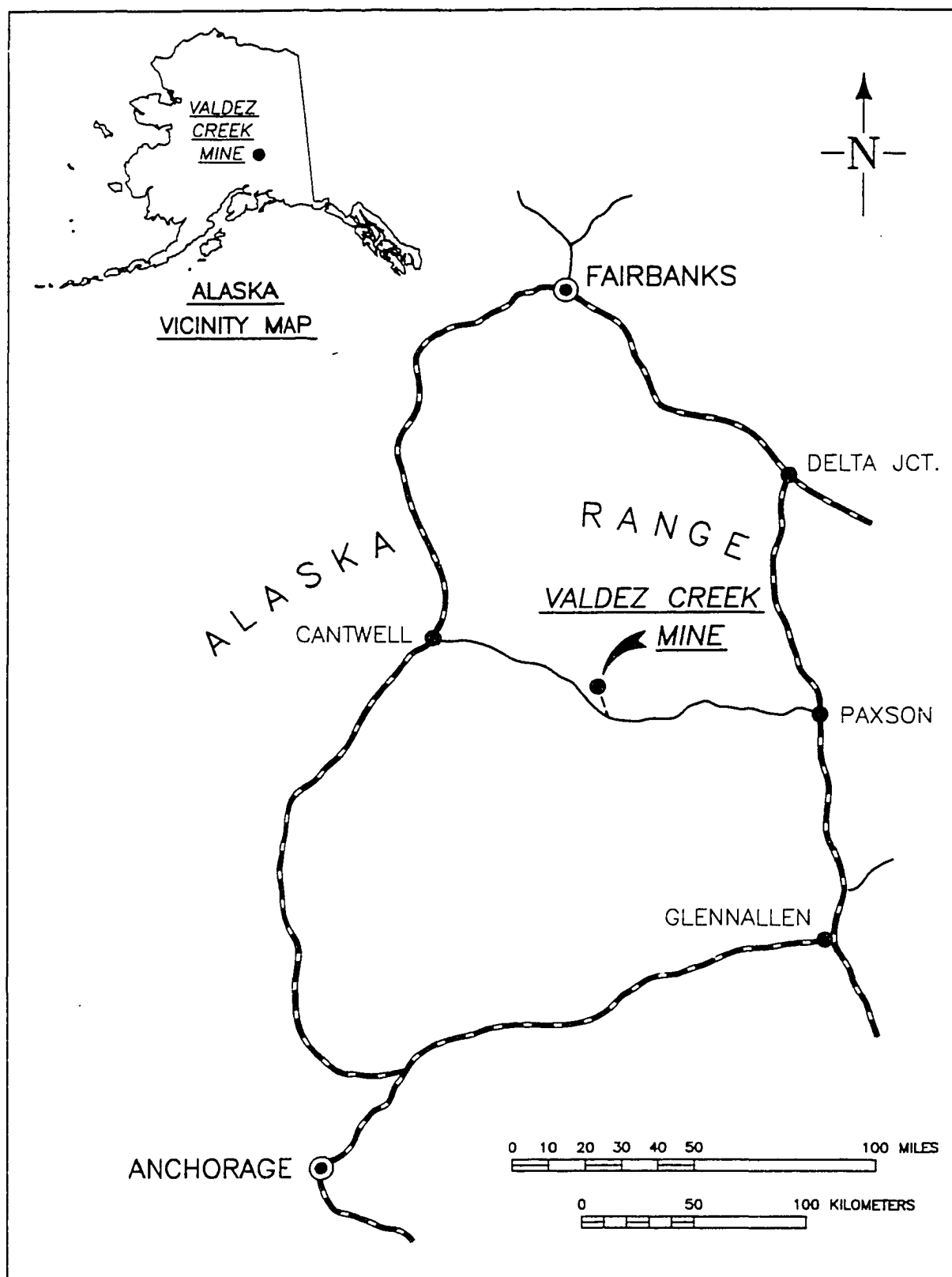


Figure 3-1 Location Map (state)

4. PHYSIOGRAPHY

Valdez Creek is on the western edge of the Clearwater Mountains, a small group of rugged mountains situated immediately south of the central Alaska Range (Figure 4-1). The Clearwaters are bounded by the Susitna River and Monahan Flats on the west, the Gulkana Uplands to the south, and by the MacLaren River on the east. Valdez Creek drains westward into the Susitna River, a major drainage rising from glaciers in the Alaska Range, 24 km to the north.

The area was repeatedly glaciated during the Pleistocene, resulting in glacial deposits in the valleys and on most of the lower slopes. These deposits tend to have low relief. Bedrock outcrop is rare below 1200 m but becomes common above this elevation. Minimum elevation in the study area is just below 760 m at the confluence of Valdez Creek and the Susitna River, and maximum elevation is 1913 m at the head of Big Rusty Creek, a tributary to White Creek, one of two major southern tributaries to Valdez Creek.

Valdez Creek flows in a hanging valley with a floor at 950 m. The modern drainage has cut a steep-sided, 30 to 50 m deep canyon through glacial deposits and bedrock as it traverses 3 km of Susitna lateral moraine. It eventually grades to the Susitna River at 760 m (Sheet -- Quaternary Geology of the Valdez Creek Area). Several times during the Pleistocene, similar canyons were cut and later buried, forming the paleochannels that contain the placer gold deposits at the Denali Mine.

The drainage pattern of Valdez Creek is similar to that of most glaciated east-west drainage systems in the higher northern latitudes. The north side of the valley has first and second order drainages that are rarely over 3 miles long, while the south side of the valley has numerous well developed second and third order drainages that commonly exceed 3 miles in length. Virtually all of the southern drainages begin in cirques that contain rock glaciers, some of which are still active. There are no cirques on the north side of the valley.

A two stage valley is evident in the Valdez Creek valley. The lower valley has a floor between 950 and 1060 m. An upper, older valley level is defined by a distinct bench at 1250 to 1340 m elevation (Sheet -- Quaternary Geology of the Valdez Creek Area). The bench is a

prominent feature of the north side of the valley and can also be seen on the south side between Roosevelt Creek and Grogg Creek.

The morphology of two low passes into the valley indicates that, during maximum glaciation, ice from the north and from the east may have entered the valley. A 1100 m pass with essentially no relief connects Roosevelt Creek with Pass Creek to the east and provided miners with access from the east in the old days.

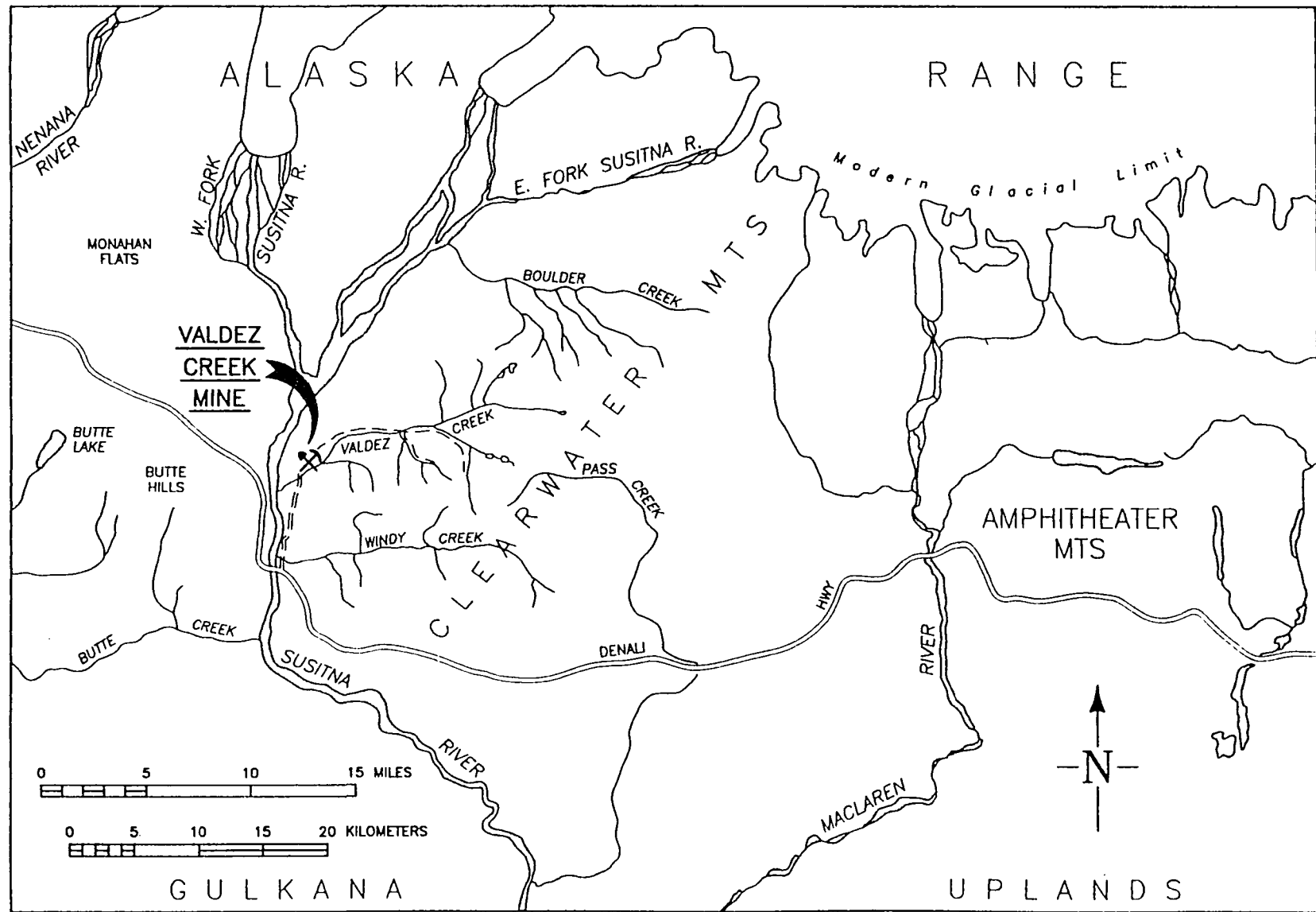


Figure 4-1 Regional Location Map

5. CLIMATE AND VEGETATION

The Clearwater Mountains are a small mountain range situated just south of the Alaska Range and north of the Talkeetna Mountains. The Clearwaters are in the rain shadow of the Talkeetnas for many storm tracks, and the Alaska Range blocks some of the extremely cold arctic air masses. Weather data are available from three stations that are in locations roughly equivalent to Valdez Creek (Leslie, 1989). One of these, the Gracious House, located 6.5 km (4 mi) from the Valdez Creek Mine, provides a record of the local climatic conditions. Unfortunately, data for the late winter and early spring months are missing. The other two stations are at Cantwell and at Paxson, located 76 km (47 mi) west and 101 km (63 mi) east, respectively. They are also on the south side of the Alaska Range, but are near major valleys that pass through the range. Average temperature and precipitation for these stations, along with Anchorage and Fairbanks, are given in Table 5-1. Monthly temperature distributions indicate that the Gracious House has cool summers, similar to Paxson and Cantwell and cooler than both Anchorage and Fairbanks, but that it has cold winters, similar to Fairbanks. Therefore the average yearly temperature for the Gracious House is probably colder than Fairbanks. Precipitation trends for the Gracious House are similar to those at Cantwell, indicating that a full year's precipitation probably averages around 500 mm (20 in). Snow pack ranges from 0.3 to 1 m (1 to 3 ft) depending on month, year, and location. The average elevation of greater than 800 m (2600 ft) and inter-mountain position have a strong influence on the local climate.

Table 5-1 Average yearly temperature and precipitation for selected Alaskan stations.

LOCATION	PERIOD	LENGTH (yr)	MEAN TEMPERATURE		TOTAL PRECIPITATION	
			(C)	(F)	(mm)	(in)
THE GRACIOUS HOUSE	1959-1978*	19	-4.0	24.8	386.08	15.20
CANTWELL AIRPORT	1941-1976	35	-3.7	25.3	495.05	19.49
PAXSON	1975-1987	12	-3.5	25.8	537.72	21.17
FAIRBANKS	1949-1987	38	-3.1	26.4	263.14	10.36
ANCHORAGE	1952-1987	35	2.0	35.7	390.40	15.37

* Data missing for February, March, April, May. Precipitation only is missing for January (Leslie, 1989)

Timberline in the western Clearwater Mountains is at approximately 950 m (3100 ft). Because this is roughly the elevation of the mouth of the Valdez Creek valley, there are no trees in the valley. Vegetation below timberline is black spruce, willow, alder, sedges, and mosses. There is not a significant brush zone at timberline. Above timberline, the vegetation consists of sedges, grasses, and mosses, with willow and alder occurring on the flood plain.

There is no permafrost at the Valdez Creek Mine, at Lucky Gulch (to 1300 m elevation), or at White Creek. Permafrost did, however, form during this century under the old ditch that served the historical Denali Mine. Rock glaciers are found in all north facing cirques in the valley (generally above 1200 m). Air-photo interpretation indicates, and Smith (1981) reports, that a few are still active and thus are “permanently” frozen. The nearest active glacial ice is 24 m (15 mi) north at the Alaska Range front in the West Fork of the Susitna River.

6. HISTORY

6.1. DISCOVERY

In February of 1903 an expedition of experienced prospectors left Valdez to prospect the upper Susitna River. They crossed the Chugach Mountains via the Valdez Glacier to the Klutina River. They then proceeded north by way of St. Anne Lake, Tazlina Lake, Lake Louise, Susitna Lake, and finally to Tyone Lake where they set up their base camp. After having little success in prospecting the eastern Talkeetna Mountains, they broke camp and continued north. Just above Tyone Lake, the Susitna River forks. At this point the party split up; one party took the eastern fork, now known as the MacLaren River, and the other party, led by Peter Monahan and including J. C. Clarkson, John M. Johnson, and James S. Smith, took the western fork. The Monahan party discovered gold on Galina Creek (original spelling) below the mouth of a narrow bedrock canyon. Working 15 days, they managed to pan and sluice 3110 gm (100 oz) of gold, worth \$1100 at the time (Dessauer and Harvey, 1980). They renamed the creek Valdez Creek after their hometown.

In 1904 the discovery party returned with a new partner, Bill Grogg. During the season's work they discovered that the gold grades dropped off at a certain point as they progressed upstream. This paradox was explained in the fall when they observed alluvial gravel in a buried channel exposed 20 m above the north bank of the deeply incised modern creek (Dessauer and Harvey, 1980). Monahan named the channel the Tammany Channel after Tammany Hall in New York, as a tribute to the Democratic Party. The Tammany Channel gravel proved to be very high grade and was the focus of the majority of the mining activity in the district until the 1980's. The Monahan party left Valdez Creek after the 1904 season with \$30,000 worth of gold (45,100 g; 1450 oz). The many other miners that followed them left disappointed due to the deep overburden, lack of water on some claims, and the lack of gold on the north side of the creek.

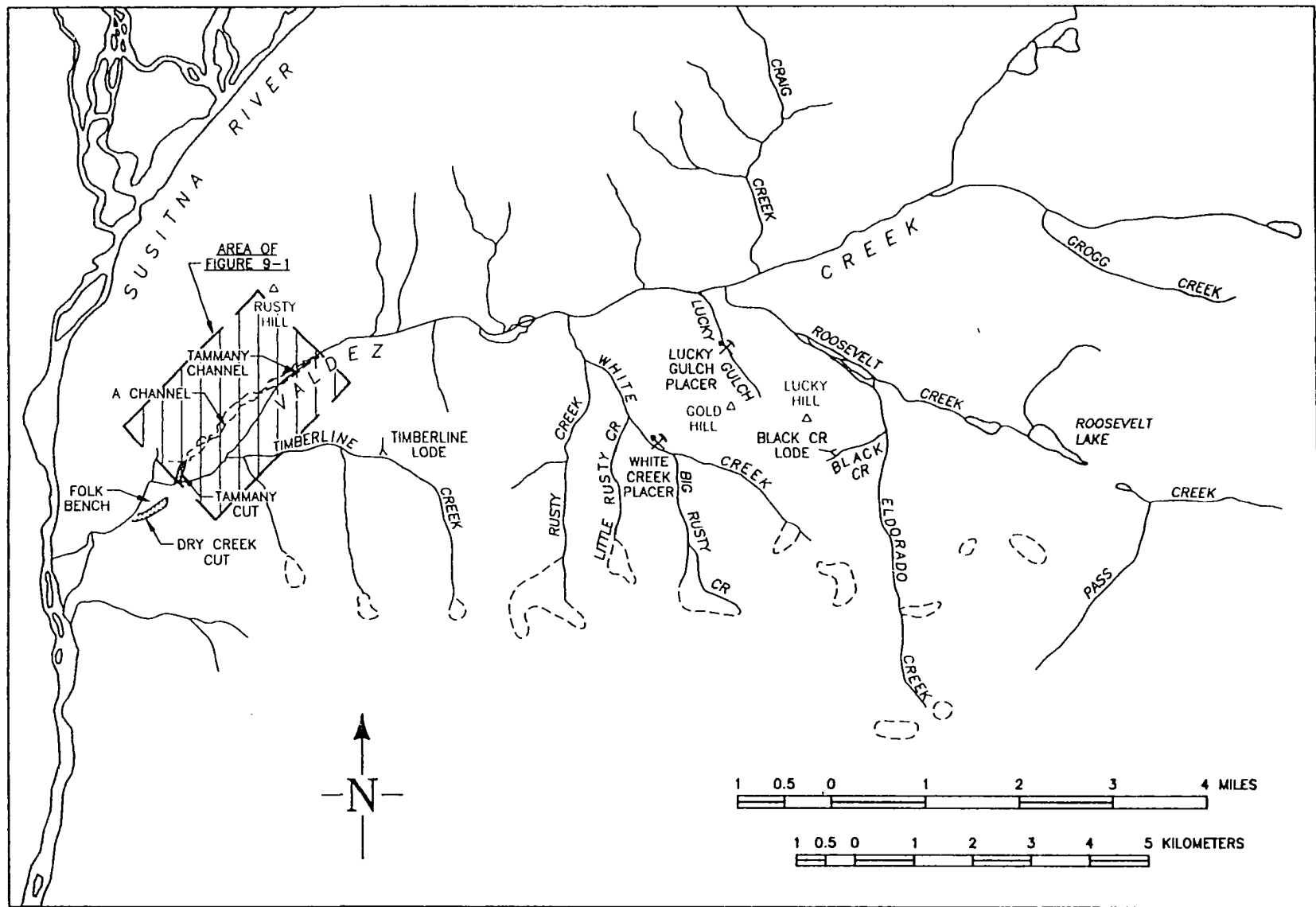


Figure 6-1 Location Map - Valdez Creek Drainage

6.2. EARLY DAYS

Underground work on the Tammany Channel began in earnest in 1907 (Figure 6-1). By the end of the 1912 season, 365 m of drift had been driven that averaged 8 m (26 ft) wide by 6 m (20 ft) high producing \$160,000 (240,700 g at 41 g/m³; 7740 oz. gold at 1.0 oz/yd³) (Dessauer and Harvey, 1980). In 1913 the operation shifted to hydraulic mining, which continued until 1918. Production figures for this period are sketchy, but the grade supposedly averaged 41 g/m³ (1 oz/yd³). Mining ceased from 1919 to 1922, apparently due to lack of profits and a shortage of risk capital during the early post-war years.

Production began again in 1923 with hydraulicking and underground drifting. Hydraulicking on the Folk Bench (Figure 6-1) began about 1928 and continued until 1936. This mining was on the downstream extension of the Tammany Channel on the south side of Valdez Creek. The Dry Creek Cut is the result of this activity.

Underground mining began in earnest again in 1934 with drift mining on the Tammany Channel (north of Valdez Creek). This activity ended on October 16, 1942, by edict of the U.S. War Production Board, which shut down all non-essential mining during World War II. During the pre-war period, a number of shafts were sunk to provide ventilation for the miners in the long drifts. The total length of the drifts is not recorded nor is the production, but 1937 and 1938 were supposedly record years (Smith, 1941). A few of the miners from this period live in Cantwell today.

All gold mining in Alaska and the rest of the U.S. was in a protracted slump after World War II, primarily due to inflation and the fixed price of gold, but also due to the rising cost of equipment. The Valdez Creek area saw little activity during the post-war era.

6.3. OTHER AREAS

The entire Valdez Creek drainage and much of the surrounding country were thoroughly prospected during two gold rushes. The first was in 1904 after the initial discovery by the Monahan party in 1903. There was a second small rush after the Timberline lode gold deposit was discovered in July of 1925 by J. M. "Laughing Ole" Olsen.

Activity on the Timberline lodes included a 20 m (65 ft) drift and a 15,000 kg ball mill (Dessauer and Harvey, 1980). No production is recorded from the drift, but apparently some gold was recovered from pits dug on surface outcrops of the various gold-bearing quartz veins.

Gold was discovered in Lucky Gulch by John H. Carlson in 1904. By the end of 1908 he is said to have recovered \$40,000 (60,000 g; 1900 oz) worth of gold from this small, steep drainage. The largest nuggets found in the district were found in Lucky Gulch. One, discovered in 1909, weighed 1620 grams (52 oz) and another, found in 1910, weighed 990 grams (32 oz) (Dessauer and Harvey, 1980). Carlson went on to be an important claim owner and trader in the district from 1926 to 1949.

Other areas that saw activity included White Creek, with \$10,000 (15,100 g; 480 oz) worth of gold production recorded between 1925 and 1928. The Black Creek lode was discovered by Lawrence Coffield in the mid-30's (Dessauer and Harvey, 1980), but no production is recorded. There was also activity on Little Rusty and Grogg Creeks, among others locations.

6.4. RECENT HISTORY

Activity began in earnest again in 1980 when a group of investors put together the Denali Mining Co. Mining began in September of 1981. Anchorage-based geologic consultant Don Stevens was hired to direct the exploration and other geologic activities. It was in 1981 that the A Channel was first discovered, using geophysics and drilling (Stevens, 1986).

In 1983 Denali Mining Co. optioned the property to Valdez Creek Mining Co. This was a joint venture that included SUM Resources, a subsidiary of Sullivan Mines, Ltd., as operator of mining, and Watts, Giffis and Mquat, Ltd. (WGM), as operator of exploration. The mine went back into production in May of 1984 after an extensive exploration and reserve evaluation effort led by Jason Bressler of WGM. During the course of this exploration, the B and PL Channel segments were discovered by drilling in 1984, the WW Channel (a probable extension of the A Channel) was discovered in 1984, the J. Smith Channel was found in 1983, and the New Smith Channel was located in 1984 (the two Smith channels are separated by Valdez Creek) (WGM, 1984) (Figure 6-1). The WW and B-PL channels were mined in 1985.

From 1986 to 1990, the joint venture partners in Valdez Creek Mining Co. were CAMINDEX Mines, Ltd.; CAMBIOR Mines, Ltd.; and American Barrick Corp. In 1990, after a 12 month shut down, CAMBIOR acquired American Barrick's share of the operation and became the operator of the mine under the name CAMBIOR Alaska, Inc. The name of the mine was changed from the Denali Mine to the Valdez Creek Mine at that time.

The current mine is an open pit, truck and shovel operation. Processing is by vibrating triple screen deck and a 7 run sluice. Since 1986, mining has concentrated on the A Channel, primarily because its width allows the economical removal of the 50 to 90 m (160 to 300 ft) of barren glaciofluvial sediment that overlies the gold-bearing alluvium. Production since 1984 is summarized in Table 6-1.

Table 6-1 Valdez Creek gold production.

YEAR	OUNCES	GRA	The entire drainage has been
1984	19,627	610,	swarming with activity in recent years. There
1985	29,833	927,	are two other active mining operations: a
1986	25,996	808,	small hard rock mine at Black Creek, owned
1987	21,068	655,	and operated by the Nelson brothers, and a
1988	44,494	1,383,	small placer mine on Lucky Gulch, owned and
SUBTOTAL	141,018	4,385,	operated by Claude Morris and Jack Dunlap.
EST. HISTORICAL	33,982	1,056,	
TOTAL	175,000	5,442,	

(Valdez Creek Mining Co., 1989)

Placer exploration activity includes (but is not limited to) extensive drilling in 1986, 1987, and 1990 on claims held primarily by the Rowallen Partnership at the junction of White Creek with Valdez Creek, a single drill line in the fall of 1987 on upper White Creek on claims held by the Nelson brothers, and a shaft in unconsolidated overburden hand dug in the winter of 1986 by Kevin Thompson and Stan Kinblade adjacent to Lucky Gulch on claims held by Thompson. Development activity includes a shaft dug to bedrock in the Valdez Creek flood plain above the White Creek confluence. Lucky Hill has been the site of hard rock exploration activities, including drilling, by a company that has gone by various names, including CanAlaska and Avalon.

7. BEDROCK GEOLOGY

The Clearwater Mountains contain two distinct rock packages (Figure 7-1). To the south are metavolcanic rocks of the Amphitheater Group (Smith, 1981) of the Wrangellia terrane (Jones *et al.*, 1981). Metapelitic rocks of the MacLaren Metamorphic Belt are found to the north of the metavolcanic rocks and underlie the majority of the Valdez Creek drainage. The MacLaren Metamorphic Belt is considered part of the MacLaren Terrane by Jones *et al.* (1981). Igneous bodies of various sizes and compositions intrude the pelitic rocks. Metamorphism and plutonism are believed to have occurred in response to crustal thickening during the accretion of Wrangellia to the North America continent (Nokleberg *et al.*, 1985). Stratigraphic and structural information in this chapter is summarized from Smith (1981) unless otherwise noted.

7.1. STRATIGRAPHY

7.1.1. AMPHITHEATER GROUP

The Amphitheater Group (Wrangellia Terrane) is found south of Windy and Pass Creeks (8 to 10 km south of Valdez Creek). It is dominated by dark gray or greenish metabasalt and basaltic andesite, which occurs as bedded flows. Subordinate flow breccia, volcanoclastic debris, carbonaceous argillite, and discontinuous limestone lenses are found. Amygdules are filled with epidote, quartz, chlorite, prehnite-pumpellyite, or calcite. Rarely, native copper or bornite is found with epidote in the amygdules. Areas of intense shearing may have veinlets of quartz, calcite, hematite, and bornite.

7.1.2. MACLAREN METAMORPHIC BELT

The MacLaren Metamorphic Belt may be divided into two distinct units: a low grade unit to the south and a structurally higher, high grade unit to the north. The lower grade rocks grade from chlorite- and prehnite-bearing meta-argillite and metagraywacke north of Windy Creek, through phyllite and biotite schist near Valdez Creek, to coarser grained biotite-garnet schists north of Valdez Creek. The argillite to the south contains quartz, sericite, and biotite and

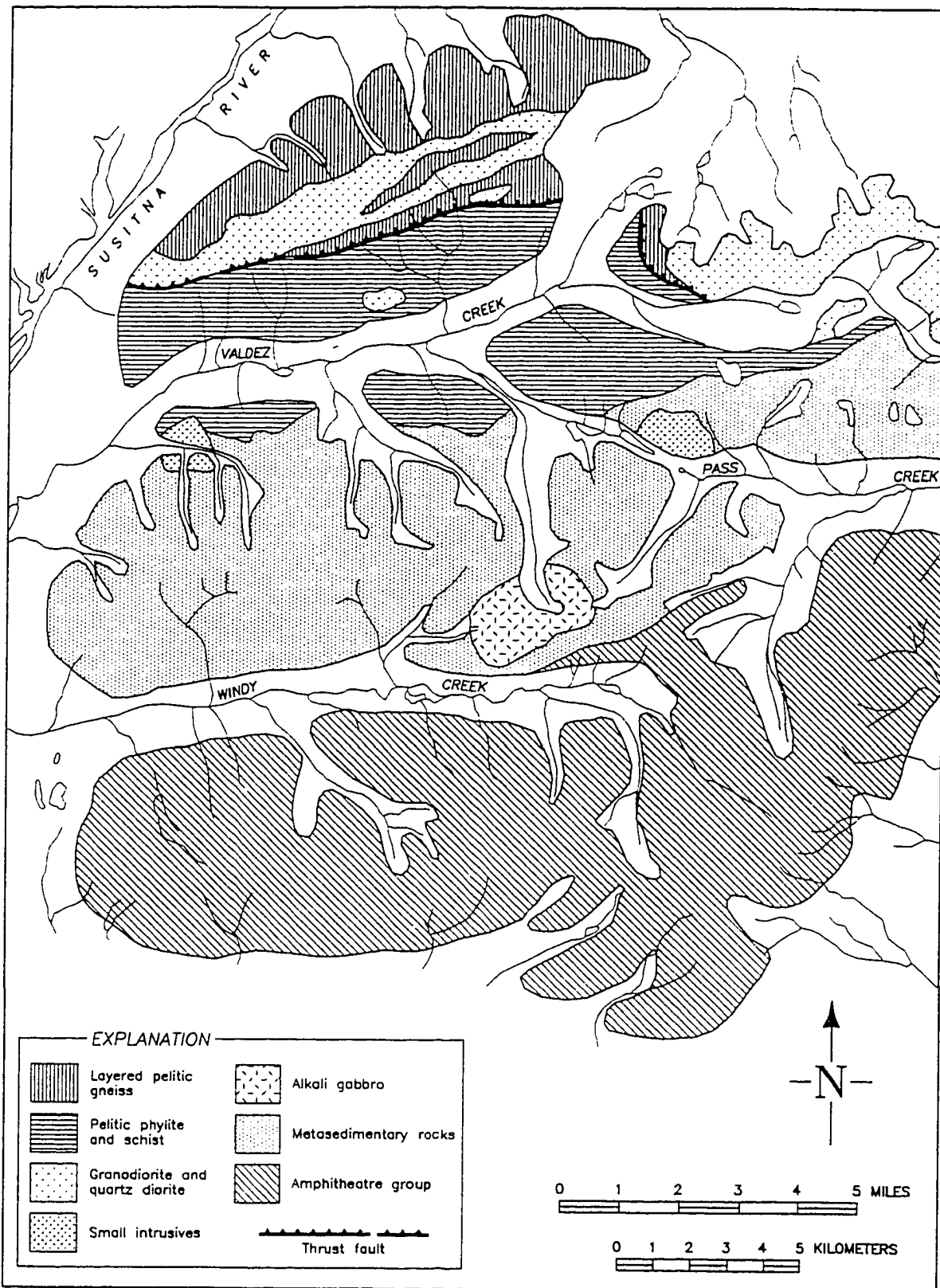


Figure 7-1 Bedrock geology, Valdez Creek area.

(from Smith, 1981)

is carbonaceous. Sedimentary structures are preserved. The argillite often grades laterally or vertically to graywacke. As the rocks become more intensely metamorphosed, poikiloblastic biotite and abundant chlorite form, resulting in a spotted phyllite. The phyllite retains some sedimentary structures. North of Valdez Creek the grade increases to schists and semi-schists containing biotite and garnet.

A thrust fault occurs at the transition to sillimanite-bearing rocks. The high grade unit occurs above and to the north of the thrust fault. This unit consists of layered gneiss and schist with kyanite, staurolite, and sillimanite. A foliated, sill-like body of quartz diorite intrudes the center of the unit. The high grade rock package forms the ridge to the north of Valdez Creek and extends further north to the Susitna River.

7.1.3. INTRUSIVE ROCKS

The oldest intrusive rock in the area is an alkali gabbro found at the head of Eldorado Creek. It is late Jurassic in age and pre-dates the regional metamorphism. The prehnite-pumpellyite facies metamorphism has blurred the plutonic textures and redistributed the elemental components.

The syn-metamorphic sill, mentioned above, occurs in the high grade metamorphic rocks forming the ridge on the north side of Valdez Creek. It is predominantly tonalite to quartz diorite in composition (Smith, 1981; Davidson *et al.*, 1992) with numerous xenolithic slivers and lenses of gneiss and high grade schist. Foliation parallels that of the surrounding metamorphic rocks.

To the east, at the heads of Valdez Creek and Boulder Creek (Figure 4-1), the high grade metapelites are intruded by the East Susitna Batholith, a composite batholith of granodioritic composition. K/Ar dating indicates an age of Late Cretaceous or early Tertiary.

Numerous small stocks, dikes, and sills occur in the area, but are restricted, almost exclusively, to the lower grade metapelitic sequence between Windy Creek and Valdez Creek. They vary widely in composition from gabbro to granodiorite. Most of the small stocks have equigranular to porphyritic textures. They are commonly partly metamorphosed with textures and metamorphic minerals similar to the surrounding metamorphic rocks. Development of epidote and chlorite is common, giving the rocks a gray-green color. The metamorphic textures and minerals indicate that the small intrusives were emplaced during the waning stages of metamorphism.

Several of the small intrusives are cut by gold-quartz-carbonate veins. These bodies are altered and have a suite of secondary minerals that includes silica, carbonates, chlorite, and pyrite. The Blackfoot and Timberline prospects are in this environment.

7.2. STRUCTURE

The dominant structural grain is N75°E. The dip is northwesterly on flows in the Amphitheater Group and in metapelites north of Valdez Creek, but between Windy Creek and Valdez Creek the strata show folding and southeasterly as well as northwesterly dips.

Smith (1981) mapped a thrust fault on the south flank of the ridge north of Valdez Creek. It trends east-northeast, parallel to foliation, and then bends to south-southeast near the East Susitna Batholith. This is a significant zone of shearing and thrusting, along which the higher grade metamorphic rocks of the MacLaren Belt were emplaced over the lower grade metamorphic rocks of the MacLaren Belt.

Numerous high-angle faults with both vertical and strike-slip movement are found throughout the area. These faults displace both the thrust faults and all generations of intrusives. A through-going, east-west-trending shear zone roughly parallels Valdez Creek on the south side of the valley. Two of the prominent lode prospects in the area have veins in fault zones (Timberline) or are at the intersection of two fault zones (Black Creek). The veins in most of the known lode prospects show evidence of shearing.

7.3. TECTONIC INTERPRETATION

The metamorphism seen in the MacLaren Metamorphic Belt and the plutonism in the area record the accretion of Wrangellia onto the North American continent (Nokleberg *et al.*, 1985; Csejtey *et al.*, 1982). Davidson *et al.* (1992) demonstrate that Wrangellia was underthrust beneath the continent, with a sense of movement of top to the south-southeast during deformation. In the vicinity of Valdez Creek, the majority of the displacement occurred as ductile shear at the thrust fault mapped by Smith (1981), with high grade rocks thrust over low grade rocks. Most of the deformation was in the low grade footwall rocks. Davidson *et al.* (1992) suggest that approximately 10 km of vertical displacement has occurred in this zone. The intrusion of the East

Susitna Batholith post-dates the main metamorphic episode because it deforms and folds the fabric of the surrounding metamorphic rock (Davidson *et al.*, 1992).

8. LATE CENOZOIC GEOLOGY

8.1. INTRODUCTION

The surficial geology is based on aerial photo mapping of the Clearwater Mountains by the author, with limited field checking in the Valdez Creek valley. The subsurface geology is based on: geologic pit mapping by the author at the Valdez Creek Mine in the A-4 pit; geologic observations over a three year period in pits A-3, A-4, A-5, and A-6; drilling-generated subsurface geologic data interpreted by the mine staff with additional interpretation by the author; and interpretation during short and long range ore reserve calculations by the author in 1988, 1989, and 1990.

8.2. SURFICIAL GEOLOGY

8.2.1. HIGH LEVEL SURFACE

The Valdez Creek valley is a two-story valley. It has an older, upper level valley and a younger, lower level, inner valley. The high level surface is a remnant of the upper level valley. The surface occurs predominantly on the north side of the valley with smaller remnants on the south side of the valley between upper Valdez Creek and Roosevelt Creek and at the head of Lucky Gulch between Gold Hill and Lucky Hill; narrow remnants appear to be present on the north side of the hill between Valdez Creek and Timberline Creek (Sheet -- Quaternary Geology of the Valdez Creek Area). The elevation of the high level surface is between 1200 m (4000 ft) and 1500 m (5000 ft). It slopes gently toward the valley center and downstream. The surface is very subdued with well developed solifluction lobes on steeper slopes. A soil profile near Lucky Gulch revealed a 40 cm (1.4 ft) thick A horizon of brown sandy loam over a 15 cm (0.5 ft) C horizon of decomposed pelitic schist (local bedrock). The A horizon contains approximately 1% erratic clasts.

The distribution of remnants of this high level surface indicates that the Valdez Creek drainage may have originally included what is now upper Boulder Creek to the north (Figure 4-1). Evidently, Valdez Creek originally drained from the northeast through what is now a broad, high pass occupied by small lakes (extreme upper center of Sheet - sections 21, 22, and 28). This interpretation is based on the following observations:

1. The high level surfaces preserved on the south side of modern Valdez Creek and east of Roosevelt Creek and the surface on the west side of Peak 6223 appear to be remnants of a single gently curving surface. Modern upper Valdez Creek cleaves this gently curving surface.
2. The geomorphic character of the valley of Grogg Creek and upper Valdez Creek is quite different from the lower portion of Valdez Creek. The upstream valley is a single-story valley with a classic glacial "U" shaped profile. The "U" shaped profile continues to a higher elevation than the elevation of the high level surface, indicating that a wide upper level valley never existed in this part of the drainage.

The high level surface in Valdez Creek valley appears to have been formed during an extensive glacial episode. The current minimum elevation of surfaces that were ice-scoured during this episode is about 1280 m (4200 ft). A rough estimate of the upper limit of glaciation is about 1520 m (5000 ft), indicating an ice thickness of about 240 m (800 ft). This estimate is based on scattered erratics found on the gently sloping ridge top northeast of Rusty Hill and the transition from smooth, apparently glacially modified topography to irregular, apparently unglaciated topography at higher elevations further east on this same ridge.

The high level surface appears to have once been regionally extensive. It can be readily traced across the Susitna River to the flat topped hills in the Gold Creek/Butte Lake area to the west (Figure 4-1). The surface is at approximately the same elevation as a similar high level surface in the Amphitheater Mountains (Figure 4-1) and is probably of the same age. Péwé (1961, 1965, 1975) believes the surface in the Amphitheater Mountains formed during the Darling Creek Glaciation. He suggests that the surface was formed during the Early Pleistocene based on its age relationship to deposits of other glacial episodes in the upper Delta River and on correlation to a high level surface in the Nenana River area.

I believe the correlation of glacial events from the Amphitheater Mountains all the way to the Nenana River on the other side of the Alaska Range is sound, and that the high level surface in the Valdez Creek valley and in the Gold Creek/Butte Lake area strengthens this correlation. First, the Valdez Creek and Gold Creek/Butte Lake surface fills a major gap between the Amphitheater Mountains and the Nenana River remnants because of its intermediate location (Figure 3-1 and

Figure 4-1). Remnants of this surface can be readily traced from the Amphitheater Mountains, through the Valdez Creek area, to the head of the Nenana River valley, where the river turns to the north and transects the Alaska Range. Secondly, the Valdez Creek and Gold Creek/Butte Lake surface is at approximately the same elevation as the surface in the Amphitheater Mountains. Finally, the Alaska Range is actively rising (Wahrhaftig, 1958). Mt. Deborah, Mt. Hess, and Mt. Hays, at the head of the Susitna and MacLaren Rivers, indicate that this part of the Alaska Range is still actively rising. Thus, it is reasonable to infer that these high erosional surfaces are products of the same processes. They have been uplifted and dissected during late Cenozoic uplift. All of these surfaces are low relief and show evidence of having been scoured by very old glaciation. The principal difficulty and unresolved question is not correlating east-west, but is in correlating the relatively short distance north-south across the Alaska Range. Although I think the correlation is valid, it is a topic for further research.

Wahrhaftig (1958) and Péwé (1975) believe this surface was formed during the Browne Glaciation of Early Pleistocene age. More recent work by Thorson (1986) has reevaluated the glacial history of the Nenana River. Thorson presents evidence that the high level surface predates the Browne Glaciation, and that the Browne glacial deposits were deposited on the pre-existing surface. Thorson, therefore, believes that the surface is older and probably formed near the Pliocene/Pleistocene boundary about 2 Ma. He believes the surface is related to a glacial episode of this age that he names the Teklanika Glaciation. A similar relationship is found in Valdez Creek valley with the Craig Creek glacial moraines (next section) deposited on the pre-existing upper level surface. I believe the upper level surface in the Valdez Creek valley is of the same age as the high level surface found in the Amphitheater Mountains and on the north side of the Alaska range in the Nenana River valley. The associated glaciation will be referred to here as the Clearwater Glaciation. The upper level surface represents the Clearwater Glaciation; no deposits (with the exception of scattered erratics) have been recognized. Glacial ice of this episode flowed into the modern Valdez Creek valley from the north, potentially transporting Alaska Range erratics into the valley.

8.2.2. PRE-WISCONSINAN GLACIAL DEPOSITS

Field evidence and aerial photo interpretation indicate that the Valdez Creek valley has been repeatedly glaciated. The only remaining evidence of the oldest glaciation that post-dates the high level surface is four very subdued moraine remnants found on the old surface on the north side of Valdez Creek in the vicinity of Craig Creek. The moraines form very low ridges with very subdued topography (0.5 to 1 m deep swales, 15 to 30 m between ridge crests). Erratics are rare (approximately 150 m apart), approximately 1 m in diameter, and half buried. These moraines are remnants of what will be referred to here as the Craig Creek Glaciation.

Ice of the Craig Creek Glaciation also appears to have entered Valdez Creek from the north. This is suggested by the position of the three moraines east of Craig Creek. The fourth morainal remnant, situated west of Craig Creek, is located on the inner edge of the high level surface. This position suggests that it is a lateral moraine deposited by a glacier in the inner valley of Valdez Creek. This indicates that the inner valley of Valdez Creek formed between the Clearwater Glaciation and the Craig Creek Glaciation.

The Craig Creek Glaciation probably correlates with the Browne Glaciation of Wahrhaftig (1958), Péwé (1975), and Thorson (1986). This correlation is based on the apparent considerable age of the moraines and their position relative to the high level surface. The Craig Creek moraines were deposited on the high level surface formed by the Clearwater Glaciation and do not appear to have been related to the formation of that surface. Similarly, the deposits of the Browne Glaciation occur on the high level surface formed by the Teklanika Glaciation (Thorson, 1986). This correlation indicates that the Craig Glaciation occurred during the Early to middle Pleistocene.

The only other pre-Wisconsinan-aged glacial deposit mapped in Valdez Creek is a small medial moraine between upper Valdez Creek and the high level pass to Boulder Creek. This till deposit is on a moderately steep slope; consequently, no morphological evidence is preserved by which to compare it with other deposits. It is pre-Wisconsin because it occurs at a higher elevation than any Wisconsinan deposits in the same area. It is tentatively assigned to the Craig Creek Glaciation because of its position relative to other known Craig Creek deposits and relative to the high level surface. However, it may be younger than Craig Creek and correlate to other

intermediate aged pre-Wisconsinan glaciations tentatively mapped on the south flank of the Clearwater Mountains but not recognized in the Valdez Creek valley.

8.2.3. LATE WISCONSINAN GLACIAL DEPOSITS

Broad lateral moraines of the late Wisconsinan age Hatchet Lake Glaciation border the Susitna River. The lateral moraines extend along the length of the Clearwater Mountains from the Alaska Range to the terminal moraine located 6 km south of the Clearwater Mountain front. The Hatchet Lake moraine (Kachadoorian *et al.*, 1954) is the product of a very large glacier. It has numerous small and large lakes and closed depressions. It is generally heavily vegetated with spruce, brush, or occasionally bog vegetation. On ridge crests, numerous erratics of all sizes are well exposed.

Hatchet Lake age drift covers the majority of mid Valdez Creek, White Creek, and the east half of Roosevelt Creek. The deposits are mostly lateral and recessional moraines with very little knob and kettle topography. Valdez Creek is above timberline, but these deposits tend to be well vegetated with sedges and low brush. With the exception of the lack of trees and of knob and kettle topography, these deposits are generally comparable to those of the Susitna Glacier. In particular, the vegetation cover is similar: vegetation is well established and bare ground and cobbles are rarely exposed other than at ridge crests. Soil profiles are variable, but there is generally about 15 cm of moderate to dark, brown to red-brown A horizon. Clasts exhibit minor weathering only. The variability in soil profiles may be due, in part, to loess accumulation. Morphological features are well preserved.

The Hatchet Lake Moraine was first recognized by Kachadoorian *et al.* (1954). Smith (1981) published a compilation map by D.R. Nichols, U.S.G.S., that is apparently the first published reference to the late Wisconsinan Hatchet Lake Glaciation. The timing of this event has been corroborated by Thorson *et al.* (1981), who report radiocarbon dates from the Tyone River Bluffs (downstream from the Hatchet Lake age terminal moraine of the Susitna Glacier) that bracket a late Wisconsinan age glacial event that they believe is Hatchet Lake equivalent. The Hatchet Lake glacial event is equivalent to the late Wisconsinan Butte Lake Glaciation in the northern Talkeetna Mountains (Welsch *et al.*, 1982; Thorson *et al.*, 1981), Denali II Glaciation in the Amphitheater Mountains (Péwé, 1961, 1965, 1975; West, 1975, 1981; Schweger, 1981), and

at least in part, to the Donnelly Glaciation in the upper and lower Delta River (Péwé, 1961, 1965, 1975; Péwé and Holmes, 1964), and to the Riley Creek Glaciation in the Nenana River (Wahrhaftig, 1958; Péwé, 1975; Ritter and Ten Brink, 1982; Thorson, 1986).

8.2.4. HOLOCENE GLACIAL AND ALLUVIAL DEPOSITS

Glacial deposits younger than those of Hatchet Lake age are found in many of the high cirques in Valdez Creek and adjacent drainages. Deposits of the younger episode also occupy most of Eldorado Creek, upper Valdez Creek and Grogg Creek, and portions of upper Roosevelt Creek and Pass Creek. The deposits of this age will be referred to here as being of the Eldorado Creek glacial event, after the well-preserved deposit of this age in Eldorado Creek. Deposits of this age are distinguished by very well-preserved morphology, thin soil development, and thin vegetation. The considerable difference in preservation, soil development, and vegetative cover suggests that the Eldorado Creek deposits are significantly younger than those of Hatchet Lake age. A younger age than the late Wisconsinan Hatchet Lake would indicate that these are neoglacial deposits.

Relict rock glaciers occupy many of the high cirques. The relict rock glaciers are distinguishable from Eldorado Creek deposits by their pristine morphology and lack of soil. Active rock glaciers, which also occupy many of the high cirques, are recognized by the lack of lichen growth on the over-steepened, active slopes. The relict and active rock glaciers may be remnants of the Eldorado Creek glacial event. Ice-dominated glaciers are not currently found in the Clearwater Mountains.

Two mappable areas of talus are shown on the Sheet included at the back of this document. Talus areas were distinguished from active or relict rock glaciers by the total lack of glacial morphology. Also, the talus in the map area generally consists of interconnected cones or mantles of debris situated at the slope break, suggesting collections of rock fall debris.

The Susitna River starts at large active glaciers 25 to 30 km upstream of the Valdez Creek confluence. Consequently, the river has a broad flood plain with numerous braided channels. Other much smaller areas of alluvium are located along the full length of most stream channels in the map area. Only the larger alluvial areas in these streams have been mapped. Swampy areas, probably representing filled lakes and therefore including lacustrine as well as alluvial deposits,

have been included in this unit. Most alluvium on the Sheet is probably Holocene in age, though no dating has been done to establish the age or ages.

Alluvial fans are commonly found at the foot of drainages that range in size from unnamed gullies to Valdez Creek. These Holocene deposits typically mantle alluvium or till of late Wisconsinan or younger age. The current extent of the Valdez Creek fan is largely due to the bygone practice of washing all placer tailings directly into the stream.

Much of the lower portion of the sides of the valleys in the map area have been mapped as undifferentiated Quaternary sediment. These areas do not have features that are sufficiently distinct to allow them to be reliably subdivided. Many of these areas have been obscured by downslope movement or are a mix of till, talus, and alluvial fans.

8.3. THE PALEOCHANNELS AND THEIR DEPOSITS

The subsurface geology is known through the exploration and mining associated with the gold placer deposits in the buried paleochannels of Valdez Creek. Modern mining activity is centered on the A Channel (Figure 7-1 and Figure 8-1), because the high gold grade of the basal gravel in combination with the large width of the channel makes it economically feasible to strip the large thickness of sediment burying the deposit. The concentration of exploration and mining on the A Channel ultimately results in an abundance of information on the A Channel and a paucity of data on the other channels, except where they are close to the A Channel. Because of this, sedimentological descriptions in this section will be of units in the A Channel or of units burying the channel. I assume that the sedimentary units in the other channels are similar, but that they probably vary in detail.

Detailed cross sections that compile and interpret the geology in the areas that have been or will be mined have been prepared by the Valdez Creek Mine staff. A detailed presentation of that work is beyond the scope of this study. The work will be summarized in this section.

8.3.1. DESCRIPTION OF CHANNELS

Bedrock in the Valdez Creek valley and the adjacent portion of the Susitna River valley is buried beneath 30 to 90 m of glaciofluvial sediment. Modern Valdez Creek has eroded through this sediment and flows in a bedrock-floored canyon. In places this canyon has been eroded as

much as 10 m into bedrock. The front of the Clearwater Mountains and the mouth of the Valdez Creek valley are located 2 km east of the north-south flowing Susitna River. The floor of the Valdez Creek valley has an elevation of approximately 3000 ft above sea level, while the Susitna River has an elevation of approximately 2500 ft above sea level. The modern Valdez Creek canyon is eroded into the sediment and bedrock at the mouth of the Valdez Creek valley, where it drops from the hanging valley to the level of the Susitna River.

There are four buried paleochannels incised into bedrock at the mouth of the Valdez Creek valley (Figure 7.1). Presumably, each was formed in a manner similar to the modern Valdez Creek canyon. The channels that have been identified include the A Channel, the B-PL Channel, the Tammany Channel, the Smith Channel, and the South Channel. The channels show varying degrees of development as expressed in their depth, width, gradient, and up-valley extent. The amount of development is a function of the length of time available for the ancient Valdez Creek to adjust its course to the local base level of the Susitna River during each channel-forming period.

The A Channel is a compound feature with an inner canyon cut into a well developed bench. Since the bench and channel were formed during the same channel-forming period, they will be collectively referred to as the A System. The A Bench is the widest and most persistent paleochannel. It is the dominant feature in the bedrock valley of Valdez Creek, occupying most of the width of the valley bottom and locally attaining a maximum width of 180 m (600 ft). It is traceable far up Valdez Creek. The A Channel is a 10 to 20 m wide canyon cut approximately 5 m into the A Bench.

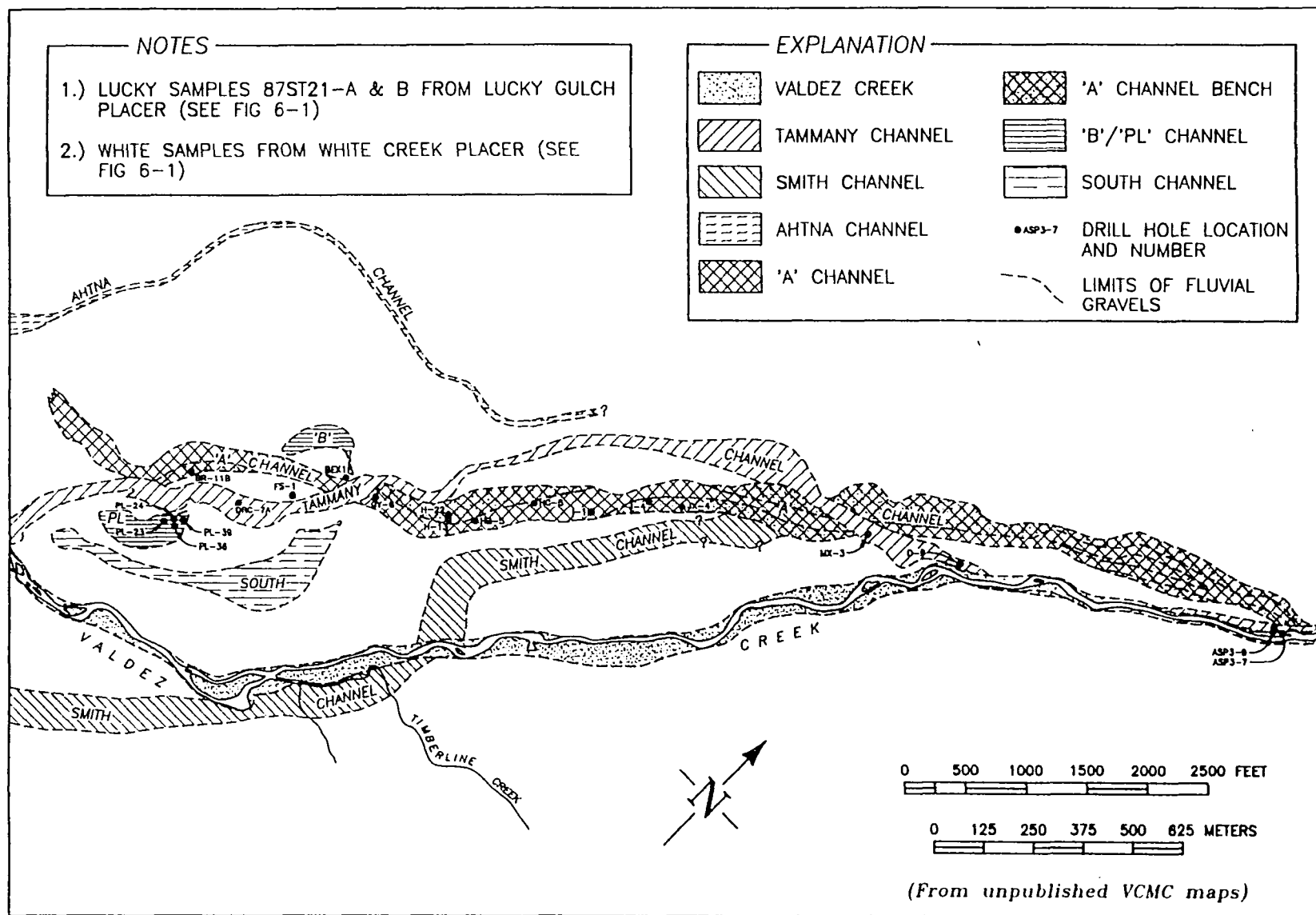


Figure 8-1 Map of Valdez Creek paleochannels and location of samples used in this study.

The Tammany Channel is the next most extensive channel and is also traceable far up the valley. The Tammany Channel tends to have steep sides and ranges from 5 to 15 m wide. Its depth relative to the A Channel varies, but it is generally cut 7 to 9 m deeper into bedrock.

The B-Pl Channel is actually two channel remnants located at the hanging valley mouth. These two segments appear to be remnants of a single paleochannel that was eroded 15 m (50 ft) less deeply into bedrock than the A Channel.

The Smith Channel is less extensive. It has been identified only at or below the mouth of the hanging Valdez Creek valley. The Smith Channel occurs at approximately the same depth as the A Channel at the valley mouth, but becomes at least 6 m (20 ft) deeper than the A Channel in the vicinity of the Tammany Cut.

The South Channel may be a fifth paleochannel. It is poorly developed and little is known about it. It will not be considered further.

A sixth channel, the Ahtna Channel, is located 300 to 450 m (1000 to 1500 ft) northwest of the main paleochannel sequence. The position, profile, and stratigraphy of this channel suggest that it is a proglacial, ice-marginal channel rather than a typical paleochannel of Valdez Creek.

8.3.2. GENERALIZED STRATIGRAPHY AS OBSERVED IN THE A CHANNEL

The basal unit in the A Channel, on the A Bench, and in the other channels is known as the "fluvial gravel" by the mine staff (long section, Sheet -- Quaternary Geology of the Valdez Creek Area). This is the gold-bearing unit. It varies in character somewhat from channel to channel and from place to place in a given channel, but is generally a massive to crudely bedded, clast-supported, pebble and cobble dominated, fluvial deposit. The thickness varies from less than a meter to about 10 meters. It varies from moderately well sorted to somewhat poorly sorted. The fluvial gravel is readily distinguished by its dark gray color, due to the high ratio of argillite and phyllite clasts relative to clasts of granitic clasts. The fluvial gravel is interpreted to represent a lag deposit formed at the bottom of an aggrading stream.

Glacial drift dominates the stratigraphy at the mouth of the Valdez Creek valley, where it is found immediately above the fluvial gravel and where it extends to the surface. It is 30 m thick

in this area. Progressing up-valley, the till becomes thinner, eventually occurring as isolated patches found only near the surface. It is generally unsorted, with roughly 10% boulders, 20% cobbles, 20% pebbles, 20% sand, 20% silt, and 10% clay. Locally the till contains masses of deformed alluvium. There is a low ratio of argillite and phyllite clasts relative to granitic clasts in the till.

Upstream of the till at the mouth of the Valdez Creek valley, lacustrine sediment is nearly always found deposited on the fluvial gravel. The lacustrine sediment is deposited against the till at the mouth of the valley. The lacustrine sediment is typically found immediately above the fluvial gravel further up-valley as well. Smaller, isolated bodies of lacustrine sediment are also found higher in the stratigraphy, interbedded in glaciofluvial sediment. The lacustrine deposits are well bedded with alternating sand-dominated and silt-dominated layers, which range from 1 to 20 cm thick. The silt to sand ratio varies widely from section to section, but averages approximately 1:1. The sand layers may show no sedimentary structure, but are usually either normal or reversely graded or show various types of ripple sequences. Clay dominated layers occur, but are less common. In some areas, 1 to 3 cm gravel layers occur. Dropstones are occasionally found. This bedding is interpreted to be rhythmites (Ashley *et al.*, 1985) deposited by density underflow currents and, as such, are the distal equivalent to delta bottomsets. Many sand and silt layers were deposited during a single meltwater season. The clay layers represent winter deposition.

Two key stratigraphic relationships were observed. First, the lacustrine deposit appears immediately upstream from the till and seems to have been deposited against the till. Locally the bedding in the lacustrine sediment is deformed, and till was deposited directly over it, suggesting that the lacustrine sediment was deposited against glacial ice or till and then was deformed as the glacier expanded and overrode the lake sediment. Secondly, in other areas the lacustrine unit coarsens and grades into delta bottom sets.

Deltaic deposits are found at numerous locations in the sequence, but are more common in the lower part. The most outstanding feature of this unit is the steeply dipping beds of the delta foresets, often dipping as much as 30°. Deltaic deposits range from 3 to 15 m thick and may have individual beds that can be traced for over 30 m. The deposits are well bedded and contain, on the average, 10% boulders, 20% cobbles, 30% pebbles, and 40% sand in the foreset beds. The deltaic

sediments become finer as the dip flattens, and they can be seen to grade into lacustrine sediment in exceptionally good exposures. Granitic clasts predominate over argillite and phyllite clasts. The deltaic deposits dip both up and down Valdez Creek. This important observation indicates that the deltas were deposited, at different times, by streams from the Valdez Creek valley and streams from the Susitna valley.

Generally, the next higher unit in the sequence is glacial outwash representing a valley train (valley sandur). This unit is generally poorly to moderately bedded, moderately sorted, and clast-supported. It can be very coarse, with 30% boulders, 30% cobbles, 20% pebbles, and 20% sand. It ranges from 5 to 15 m thick and also has a high ratio of granitic clasts to metapelitic clasts. A distinctive feature of this unit is the lack of sedimentary structures other than the laterally continuous, flat dipping beds.

The uppermost unit is also glacial outwash. It is distinguished from the previous unit by its well developed trough cross-bedding and finer clast size. The upper outwash contains very few boulders, 30% cobbles, 40% pebbles, and 30% sand. It is of approximately the same thickness as the lower outwash unit and has the same lithology. The uppermost unit is probably a more distal outwash facies than the previous unit.

A number of key features of the stratigraphy have been noted. The significance will be examined in the next section.

8.3.3. INTERPRETATION PROBLEMS

Throughout the stratigraphic description, the ratio of argillite and phyllite clasts relative to granitic clasts has been noted. This ratio is important in any interpretation of the depositional history, because it reflects the ratio of sediment local to Valdez Creek relative to sediment from outside source areas.

Less than 10% of the Valdez Creek drainage basin is underlain by felsic intrusive bedrock by area, the majority of which is granitic textured. The fluvial gravel contains roughly this percentage of granitic clasts. All of the overlying units have a much higher percentage of granitic clasts. The Susitna River, draining an area with large composite batholiths in the Alaska Range, has sediment with a much higher percentage of granitic clasts. The ratio of clast types may have been different in the Early Pleistocene when Valdez Creek apparently drained from the modern

Boulder Creek area to the north. At that time, foreign sediment could have been transported into the Valdez Creek valley by glacial ice and associated proglacial streams entering from the north during the Clearwater and Craig Creek Glaciation. Hatchet Lake lateral moraines indicate that the Susitna Glacier advanced past the mouth of the Valdez Creek valley during the Late Pleistocene and, therefore, presumably at earlier times as well. Ice marginal streams along the Susitna glacier may have discharged into the mouth of the Valdez Creek valley during these periods, depositing foreign sediment in the valley.

The deltaic deposits very graphically demonstrate the direction of flow of the streams from which they were deposited. The bedding in some deltas dip downstream (down Valdez Creek), as expected. The bedding in other deltas dip up Valdez Creek valley, demonstrating a source from the direction of the Susitna River. This evidence indicates that the Susitna Glacier and related ice-marginal streams deposited foreign clasts in the Valdez Creek.

A theory explaining the origin of the channels and the depositional history must include a Susitna River as well as a Valdez Creek source of sediment in the Valdez Creek valley. The theory must also explain the observation that gold is highly concentrated in the alluvial gravel, but is virtually absent in the overlying sediment.

The remaining problem is the formation of the multiple channels themselves. What caused the rise in base level necessary to get the stream out of a bedrock channel and wandering free to establish a new course? What caused the lowering of base level to establish a new bedrock channel? What caused the slight rise in base level necessary to leave up to 10 m of alluvium deposited in the bedrock channel?

8.4. ORIGIN OF THE CHANNELS

The formation of paleochannels, the concentration of gold, and the filling of Valdez Creek valley with sediment are interpreted to be the results of a series of glacial and interglacial events. The glacially related nature of the channels and their filling has long been recognized (Ross, 1933; Tuck, 1938; Smith, 1970, 1981). Early workers knew only of the Tammany Channel, however. After the multiple-channel nature of the deposit was discovered in the 1980's, it became evident that repeated glacial and interglacial periods are recorded in this deposit (Bressler *et al.*, 1984;

Teller and Bressler, 1988; Reger and Bundtzen, 1990; Teller, 1990). I advance the following scenario as a unified theory to explain the depositional and erosional history of the paleochannels in Valdez Creek.

The paleochannels are the direct result of repeated glaciation and deglaciation. During glacial episodes, Valdez Creek was dammed by ice in the Susitna River, glaciofluvial and lacustrine sediment filled the Valdez Creek valley, and after the ice withdrew, the creek was reestablished on top of the deep sedimentary fill. During the subsequent interglacial interval, Valdez Creek breached the morainal dam left by the Susitna Glacier, cut down through the sedimentary fill, and upon reaching bedrock, established a new bedrock channel.

During each major glaciation, glaciers in the West, Middle, and East Forks of the Susitna River extended beyond the southern front of the Alaska Range and filled Monahan Flats (Figure 8-2; for modern comparison see Figure 4-1). This is clearly seen in the modern topography left by the late Wisconsinan Glaciation. Monahan Flats was eventually filled with ice, causing some ice to exit to the west toward Cantwell and some to the south, down the Susitna River toward the Gulkana Uplands and Copper River Basin.

The Alaska Range is a considerably more significant source of ice than the Clearwater Mountains. The Alaska Range forms a major barrier to weather fronts moving north from the Gulf of Alaska or northeast from Cook Inlet. The Alaska Range in this area has numerous peaks over 3500 m, while the tallest peak in the Clearwaters is under 2000 m elevation. At the present time, there are no active ice glaciers in the Clearwater Mountains, though there are a number of rock glaciers. The Alaska Range is currently heavily glaciated, with the terminus of the West Fork of the Susitna glacier standing at the range front.

When the Susitna glacier advanced past the Valdez Creek valley during each glacial episode, the Valdez Creek glacier apparently had not advanced to the mouth of the valley. The Susitna glacier dammed Valdez Creek, forming a proglacial lake in the drainage. As the depth of glacial ice in Monahan Flats increased, the Susitna glacial ice bulged into the Valdez Creek



Figure 8-2 Approximate late Wisconsin glacial limits, Valdez Creek area.

valley, overriding the lacustrine sediment. During the melt season, sedimentation was very active, and the proglacial lake was filled by water and sediment from both Valdez Creek and the Susitna drainage.

It is not clear whether or not the Valdez Creek glacier advanced to the mouth of the Valdez Creek valley and merged with the Susitna glacier in the late Wisconsinan. It appears likely that the maximum advance of the late Wisconsinan Valdez Creek glacier is marked by the morainal remnant found in the valley bottom below White Creek between Caribou Creek and Fox Creek, approximately 4 km from the valley mouth. It is likely that earlier advances, such as the Craig Creek Glaciation, filled the length of the valley and merged with the Susitna glacier.

During interglacial periods, the glacial ice receded from Monahan Flats, Valdez Creek was left flowing on the sedimentary fill in a hanging valley, and the Susitna River reestablished at roughly its previous elevation. In its steepened lower course, Valdez Creek then cut down through the sedimentary fill left by the Susitna glacier and eventually became incised in underlying bedrock. The resulting canyon was gradually extended up-valley by headward erosion. Each newly formed canyon was absolutely independent of the course of any previous (preglacial) bedrock channel.

During the later part of an interglacial interval, Valdez Creek continued its headward erosion of the sedimentary fill, extending the bedrock channel far upstream. An alluvial fan probably formed in the lower reaches of Valdez Creek beyond the mouth of the valley. Eventually, an even gradient, graded to the Susitna River base level, was established by enlargement of the fan and deposition in the lower end of the channel. At this stage, the alluvium of Valdez Creek gradually became dominated by local lithologies. Gold was concentrated in the bottom of the channel as periodic storm events swept the alluvium from the channel and formed a lag deposit.

This cycle was repeated with the onset of the next glacial episode.

In order to estimate the time required for the channel-forming part of the cycle, consider the modern channel of Valdez Creek, which has been formed during the 12,000 years since regional deglaciation (Thorson *et al.*, 1981). During that time, Valdez Creek has eroded a channel, partly cut into bedrock, extending about 4.5 km upstream from a small alluvial fan graded to the Susitna River (Sheet -- Quaternary Geology of the Valdez Creek Area). The channel is not graded and contains accumulations of gravel only in bedrock depressions. The modern Valdez Creek channel

is much steeper than any of the buried channels, and only the lower half of the 4.5 km long incised channel lies near the elevation of the paleochannels. At the head of the canyon, the paleochannels lie about 40 m lower than the modern Valdez Creek channel. It appears, then, that the paleochannels were carved during interglacial intervals much longer than 12,000 years.

8.4.1. CHRONOLOGY OF CHANNELS

The absolute age of the paleochannels is unknown at this time. Recently reported ages from Reger and Bundtzen (1990) are shown in Table 8-1. The majority of these are minimum ages. The finite ages have large sigma values and probably also represent minimum ages (Reger and Bundtzen, 1990). Plant microfossil identification reveals an herb-dominated tundra with patches of willow and birch, and probable nearby spruce (Reger and Bundtzen, 1990). No microfossils indicative of pre-modern vegetation were identified. A broken mammoth tusk, discovered during mining in the A Channel, yielded a finite age (Table 8-1), but the large sigma value indicates that it may be a minimum age (Reger and Bundtzen, 1990). Proboscideans first appeared in Alaska at about 1 Ma (verbal communication, R. D. Guthrie, University of Alaska - Fairbanks, 1990). A discussion of the possible ages of the channels will be presented in Section 16.3, after further evidence concerning the relative ages of the channels is presented in this thesis.

Relative dating by stratigraphic techniques suffers from an exposure problem, namely that the exposed stratigraphy is only that covering the A Channel because of the preferential mining of the A Channel. Stratigraphy over the other paleochannels has only been exposed when one of the channels cuts across the A Channel or is very nearby. The second problem is in identifying significant unconformities in the stratigraphic sequence. Unconformities identified by paleosols or by differing degrees of weathering above and below a stratigraphic break have not been observed in the mine excavation. Therefore, the identification of any unconformities must be based strictly on stratigraphic interpretation. Are departures from the generalized stratigraphy outlined above due to a new erosional/depositional cycle, or are they part of the normally expected variability in the dynamic, high sediment load, glaciofluvial environment?

The relative age of the paleochannels is a topic of debate among geologists familiar with the deposit. The primary source of subsurface information is exploration and development drilling. Unfortunately, cross-cutting relationships are difficult to determine on the basis of borehole data.

Cross-cutting relationships have been observed during mining, but unfortunately, have not been well documented.

Table 8-1 Valdez Creek age dates

SAMPLE	AGE (ka)	MATERIAL	LOCATION
GX-14433	- 1.9 25.9 + 3.6	silty, organic fine sand	Pit A5, A Channel, base of upper lacustrine unit
GX-14432	>40	peat	Pit A5, A Channel, immediately overlying fluvial gravel
QL-4278	- 2.1 39.9 + 2.8	tusk - mammoth(?)	Pit A3, A Channel, fluvial gravel, 3 m below unit top
BETA-18870	>32.3	shrub twigs and branch fragments	Pit A5, A Channel, fluvial gravel

All age dates from Reger and Bundzen (1990)

The paleochannel sequence accepted by previous workers, from oldest to youngest, is B-Pl, A Channel, Tammany, and finally Smith. The main arguments for this sequence hinge on (a) the elevation of the channel bottoms and (b) indirect evidence. The bottom of each channel is at a successively lower elevation in the order given. If it is assumed that all channels developed roughly to the same degree, then this outcome can be explained in at least three ways. (1) There has been regional uplift related to the growth of the Alaska Range over the last 10 Ma (Thorson, 1986). If this were the case, the oldest channel would have been uplifted further than the others and would now therefore be at the highest elevation. Each subsequent channel would have been uplifted less and be at a successively lower elevation. (2) A different line of reasoning argues that the Susitna glacier would erode more deeply during each successive glacial episode, thus producing a successively lower local base level after each glacial episode. Each younger channel would be at equilibrium at a successively lower elevation. (3) In a similar line of reasoning, the Susitna glacier would erode a wider valley during each successive glacial episode. Assuming channel development is similar for each channel-forming event, the channels would be expected to have similar depths at similar distances from the mouth of the hanging valley. Since the mouth of the hanging valley is further up valley for each successively younger paleochannel, each successively younger

paleochannel will be deeper than the older channels in any cross section across the Valdez Creek valley.

Since the A system is the most extensive, it is convenient to consider the other channels relative to the A system. The A Bench and A Channel are obviously part of the same erosional cycle. The A Bench apparently represents a prolonged period of stability which ended with renewed downcutting and formation of the A Channel.

Most workers maintain that the B-Pl Channel segments are older than the A system based on relative elevations, assumed cross-cutting relationships, and to some extent, because only the two segments of B-Pl are preserved (WGM, 1984; Reger and Bundtzen, 1990). However, no definitive cross-cutting relationships are known (verbal communication, Jason Bressler, 1994, and Jerry O'Connor, 1995). Problems in interpretation arise because 1) the key area was mined historically, and no records exist concerning the geometry of the orebody or the geology; 2) modern mining did not occur in this area, so any evidence that might remain has not been directly observed; and 3) cross-cutting relationships are difficult to interpret because the Tammany Channel also passes through this area. The analysis of the gold grains discussed later seems to clearly indicate that the B-Pl Channel is younger than the A Channel, although definitely older than the Tammany.

The relationship between the Tammany and A Channels is best recorded by the distribution of gold grades. The gold grade in the Tammany Channel is higher immediately downstream of intersections with the A Channel and then gradually falls with increasing distance from the intersections. There is no systematic change in the gold grades in the A Channel relative to the intersections. These observations indicate that the Tammany Channel is younger than the A Channel and, where it cuts across the A Channel, it "pirated" gold.

The Smith Channel is also younger than the A Channel. This again is indicated by higher gold grades in the Smith below its intersection with the A Channel. I know of no evidence concerning the relative age of the Smith and Tammany Channels.

Because the indirect evidence yields age relations consistent with the relative elevation evidence, the sequence based on elevation is used in this thesis. Work presented later in this thesis will refine this sequence, and I will discuss my interpretation of the relative and absolute ages of the channels in Chapter 16.

8.4.2. OTHER AREAS

Gold samples were obtained from two other areas in the Valdez Creek drainage: Lucky Gulch and White Creek (Figure 6-1).

Lucky Gulch is a small, steep drainage between Gold Hill and Lucky Hill. It has been the focus of past and present placer mining activity. The largest gold nuggets reported from the Valdez Creek drainage were from Lucky Gulch. Lucky Gulch drains a remnant of the high level surface preserved between Gold and Lucky Hills. The gold-bearing gravel in this deposit is not deeply buried. Little is known about the relative age of Lucky Gulch. I think Lucky Gulch is probably a very old feature, formed soon after the inner valley of Valdez Creek was formed. I base this on the morphology of the upper part of the drainage, where the gulch does not significantly modify the high level surface, and the deep, well developed soil profiles observed in the gulch. It is probable that the sediment in the bottom of the gulch was not scoured out by later glaciations. It is not clear whether the deposit in Lucky Gulch preserves older gravel under younger gravel, or whether fluvial processes during each interglacial affected the entire depth of the deposit.

The placer gold from White Creek is from exploration drilling at a prospect near the confluence of White and Big Rusty Creeks. The gold-bearing gravel at this prospect is buried, but less deeply than at the Valdez Creek Mine. The gold-bearing gravel is not in a bedrock-incised channel, which would indicate that it could not survive glacial erosion to bedrock. However, glacial deposits of the late Wisconsinan Hatchet Lake event are deposited on top of glaciofluvial sediment in this area. I believe the gold-bearing gravel in this deposit is relatively young, based on the repeated intense glaciation that this part of the Valdez Creek drainage has experienced.

In summary, the relative age sequence postulated by previous workers is B-Pl Channel, A Bench, A Channel, Tammany Channel, and Smith Channel. However, my work (discussed below) indicates A Bench, A Channel, B-Pl Channel, and Tammany Channel. I have no new evidence on the Smith Channel. I suggest that the Lucky Gulch deposit is old and that the White Creek deposit is young.

9. EXPERIMENTAL DESIGN

9.1. INTRODUCTION

Gold grains were collected from the placer deposits in the Valdez Creek drainage in order to analyze the weathering of gold grains in the surficial environment. Gold from these paleochannels is ideal for this study because of the large range in ages of the channels. The experimental design and sampling technique are presented in this chapter.

9.2. DESIGN

Gold was collected from three of the paleochannels (A, B-PL, and Tammany), as well as from two other locations (Lucky Gulch and White Creek) (Figure 8-1 and Figure 6-1). Samples were available from both the A Channel and the A Bench, for a total of six sample locations. These six locations will be referred to as paleochannels or channels in the rest of this report. Insufficient gold was available from the Smith Channel to include this channel in the study.

The size, shape, micro-morphology, and fineness were measured for each gold grain. Each parameter was initially described as one population, and then an analysis of variance (ANOVA) was used to determine whether the channels can be distinguished based on the parameter under consideration. After all of the parameters (variables) were explored individually, a discriminant analysis was used to determine which combination of variables best distinguishes the channels from one another. A cluster analysis was also used to see if there are any hidden groupings of the gold grain data. Conclusions concerning the weathering of gold grains were drawn from the individual parameters and from the combined character of the parameters in each channel or other grouping. Finally, the relative age of the channels was re-evaluated in light of these conclusions.

9.3. SAMPLING

The bulk of the samples available for this study were from exploration and development drilling at the Valdez Creek Mine (VCM). Routine practice in the assay lab at VCM is to screen the sample concentrate into +20 and -20 mesh fractions. The gold grains in the +20 fraction are hand picked and stored in vials after final concentration. A bead of mercury is worked through the

-20 mesh fraction upon final concentration, amalgamating all of the gold in the concentrate. The gold is then liberated from the mercury with acid and heat. The amalgamation process fundamentally changes the nature of the gold for my purposes, making the -20 mesh fraction unsuitable for use in this study. Therefore, only +20 mesh grains were used throughout this study.

In order to limit the variability imposed by differing sedimentary environments, only gold grains from samples collected from within 5 feet of the bedrock contact were used. An initial inventory indicated that the Smith Channel did not have a sufficient number of +20 gold grains in this near-bedrock interval for use in this study.

The gold grains used in this study were initially collected in two ways. The majority of the grains were from exploration and development drill samples from the Valdez Creek Mine. These samples were collected using reverse circulation drilling, pre-concentration by a Denver Gold Saver, and final concentration by hand panning. All samples from the A Bench, A Channel, B-Pl Channel, and Tammany Channel were collected in this way. The samples from White Creek were also collected by the same combination of techniques. The remaining samples, from Lucky Gulch, were collected by a hand shoveling, pre-concentration with a Denver Gold Saver, and final concentration by hand panning. Are samples collected by varying techniques comparable? This important question is addressed in the next chapter.

The gold grains used in this study were selected using a stratified random sampling technique. The stratification was by channel, with gold grains randomly selected within each channel. Initially, drill holes in a channel were randomly selected until 100 grains were available, with the maximum number of grains per drill hole set at 10. Then 15 grains were randomly chosen out of the 100 for use in the study. The individual grains were selected from a drill sample by placing each gold grain on a numbered grid cell and using a random number generator to pick individual grains.

All of the grains were used in the size and shape analyses. Half of the grains were chosen at random and used in the remainder of the analyses reported (SEM and microprobe analysis of micro-morphology and fineness). A separate set of grains were used to study the effect of drilling technique on sample recovery.

All analyses were done in random order, with the exception of the microprobe work. The grains were mounted for microprobe analysis in order of shape to minimize problems in sectioning the grains and with plucking during polishing. The grains were mounted in three plugs. The plugs were not analyzed in order of size, but analysis of the grains on an individual plug were in only semi-random order.

10. DRILL STUDY

10.1. INTRODUCTION

Probably the foremost question in any study is, “How representative are the samples that were available for analysis?” The majority of the samples were collected by reverse circulation drilling, but some were collected with a hand shovel. All samples were initially concentrated by a commercial trommel/slucel apparatus known by the brand name “Denver Gold Saver”, with final concentration by hand panning. There are three questions regarding the quality of the samples:

1. Are the gold samples recovered by reverse circulation drilling representative of the gold in the ground at that location?
2. Are gold samples concentrated by a Denver Gold Saver representative of the gold in the borehole or shovel sample?
3. Can gold samples recovered by reverse circulation drilling in one area be validly compared to gold samples collected with a hand shovel in another area?

If the assumption is made that samples collected from a clean, newly exposed face by a shovel are the most representative samples that can be collected, the answer to question 1 will also be the answer to question 3.

Question 1 will be addressed in this chapter. Question 2 will not be investigated for two reasons. First, only +20 mesh grains will be used. A Denver Gold Saver is most efficient in this coarser size range; the efficiency drops off in smaller sizes. Periodic re-concentration of the Gold Saver tails by the mine staff only very rarely recovers any +20 gold that was lost during the initial concentration. In the Valdez Creek Mine assay lab, loss of +20 gold is attributed to human error rather than equipment. Second, all of the grains that are available have been processed with this device; therefore, there is no other basis for evaluating the performance of the Gold Saver. The results in this chapter were originally presented in two unpublished company reports (Teller, 1988a and 1988b).

10.2. BACKGROUND

Intense exploration and development drilling for the current large scale mining at the Valdez Creek Mine began in 1984. This work was done by WGM, of Anchorage, Alaska, for Valdez Creek Mining Co. At that time, WGM evaluated a number of the common placer drilling techniques to determine which was the best technique under the local conditions. Churn drilling (the most common placer drilling method), reverse circulation drilling, and rotary drilling were compared. Reverse circulation drilling proved to be the best technique based on drilling speed, volume recovery, and gold recovery (WGM, 1983). Reverse circulation has been the only drilling method used at the Valdez Creek Mine since 1984.

Any placer drilling method gives, at best, only an approximation of the gold grades in the area drilled. This is due partially to the high unit value of gold and the erratic distribution of gold in the gravel, and partially to problems associated with the drilling itself.

The placer gold distribution problem was thoroughly investigated by Clifton *et al.* (1969). The size of sample necessary to produce reliable results is a function of the average size of the gold grains and the number of gold grains per unit of gravel. If the gravel contains only a few large grains, a very large sample is required. On the other hand, if the gravel contains many small grains, a smaller sample is adequate.

The second problem is simply a matter of economics. Just a few grains in a sample indicate that the ground is of economic interest. Diamonds are an extreme example where a single grain in a small percentage of the samples is of economic interest.

With drilling, the problem is recovery. The recovery problem is twofold. First, there is the problem of recovering the same volume of gravel as represented by the size of hole drilled. Second, there is the problem of recovering all of the gold in that initial volume of gravel. Too much gravel may be recovered if, for instance, the gravel is relatively fine grained and the sides of the hole wash in. On the other hand, not enough volume will be recovered if the gravel is coarse and well washed, so that cuttings are washed into the interstitial spaces. The gold recovery problem is due to the density of placer gold relative to normal gravel. Gold is approximately 7 times denser than silicate rocks. Depending on the drilling technique, the gold and gravel are either

recovered by bailing (churn drilling) or brought up the drill stem by fluid pressure (reverse circulation and rotary drilling).

The focus here is on reverse circulation drilling, a method that uses fluid pressure to bring the cuttings to the surface. The fluid is compressed air mixed with variable amounts of groundwater. Gold may be lost because the fluid washes out a cavity at the bit face and the gold is blown ahead of or to the side of the bit, or because the gold is blown into interstices in coarse, well sorted alluvium. Gold also may not be recovered in the sample from the depth where it originally occurred, but may be recovered in samples from deeper in the hole. This would occur if the gold that is blown ahead of the bit goes up the drill stem at a slightly later time. It could also occur in the stream of cuttings that is being forced vertically up the drill stem. If the fluid pressure is inadequate, heavier material (gold) would not travel up the drill stem as fast as lighter material (silicate rocks).

The way a particle behaves in a fluid is a function of its size, weight, and shape. The weight and size of a particle are directly related. Weight is particularly important with gold particles because of the high density of gold. The best way, then, to evaluate how representative drilling samples are is to look at the weight and shape distributions of the recovered gold grains.

10.3. EXPERIMENTAL DESIGN

Two sets of samples from the same area were compared. One set was collected by hand with a shovel and, therefore, should most closely represent the *in situ* gold; the other was collected by reverse circulation drilling. The population parameters for the shape and weight of the grains were used as the basis of comparison. The average grade was not considered.

Corey shape factor, or CSF, (Corey, 1949; Tourtelot, 1968) is a widely used measure of the shape of sedimentary grains and will be used in this thesis. CSF is defined as follows:

$CSF = \text{Corey shape factor}$

$t = \text{thickness}$

$l = \text{length}$

$w = \text{width}$

$$CSF = \sqrt{\frac{t^2}{l \times w}}$$

10.4. HAND SAMPLES

In the fall of 1987, mine personnel collected 32 samples for grade control and to evaluate a potential western extension of the A-4 pit. These samples were collected as 0.5 to 2.5 meter vertical channel samples that were approximately 20 cm in depth and width. The sample interval extended upward from the bedrock contact. (In formal sampling terms, these samples are probably of higher quality than a grab sample, but do not meet the standards of a formal channel sample.) The sample locations are shown in Figure 10-1. A stratified random sampling approach was used to choose a subset of samples for this study. The sampled area was divided into 4 areas (Figure 10-1), and 3 samples were chosen at random from each area. Only 2 of the original 5 samples in area 3 contained +20 gold. This resulted in a total of 11 samples being chosen. A maximum of 10 gold grains were picked at random from each sample. In samples that had less than ten +20 grains, all of the +20 grains were used. A total of 82 gold grains were selected. These grains were then given a number, in random order, that was used for labeling the grain and determined the processing order. The weight, length, width, and thickness were measured for each grain.

A statistical summary of the data is shown in Table 10-1, and the raw data are presented in Appendix I. Considering the entire population of 82 grains, the weight of the grains is lognormally distributed and the CSF is normally distributed (Figure 10-2 and Figure 10-3, respectively). Log weight does not depart significantly from normal, nor does it appear that the sample is composed of more than one population. CSF is better described by a normal distribution than by other distributions, but it is not ideal. Subpopulations are not evident in the distribution.

A scatter plot of CSF versus log weight (Figure 10-4) shows a small variance in CSF, a high variance in weight, and that CSF is independent of weight (correlation coefficient of -0.186). The results indicate that the grains are uniformly flat, with a mean CSF of 0.23, and have a geometric mean weight of 49.0 mg.

The sample population was subdivided into four parts in order to gain an understanding of the general applicability of the results of this study. The areas used in stratified random sampling were used as grouping variables to subdivide the population. An analysis of variance (ANOVA) was used to determine if any of the areas had significantly different mean weight or shape. There is no difference between the mean CSFs of the four areas, but at least one group has a geometric mean weight unequal to the other group means at the 95% confidence level. A t test indicates that, at the 95% confidence level, group one is different from the other groups based on its weight. The gold grains in Area 1, the first subpopulation, have a geometric mean weight of 23.4 mg, while Areas 2, 3, and 4 form a second subpopulation with a mean weight of 67.6 mg.

10.5. DRILL SAMPLES

Twenty-four drill holes were chosen as representative of the same area as the channel/grab samples previously analyzed. These holes are shown on Figure 10-1 and are tabulated in Appendix I. All of the holes are reverse circulation drill holes drilled by Penn-Jersey Drilling Company of Wasilla, Alaska, using a 6-inch tri-cone bit. All sample processing was done by a Denver Gold Saver with final concentration by hand panning--the same method used with the samples that were collected by hand. Of the 24 drill holes, 13 had no gold recovered or the samples, unfortunately, were lost. The -20 mesh and +20 mesh gold from six holes was amalgamated, rendering the +20 gold unusable for this study. Five holes had at least one grain of +20 gold in the bedrock interval. In order to most closely approximate the channel/grab intervals, the first sample interval above bedrock, or no more than two feet into bedrock, was used (Appendix I). Because the selection of drill holes was strongly influenced by the loss of all 1984 drill samples (>50%), the sample selection was not entirely random. No

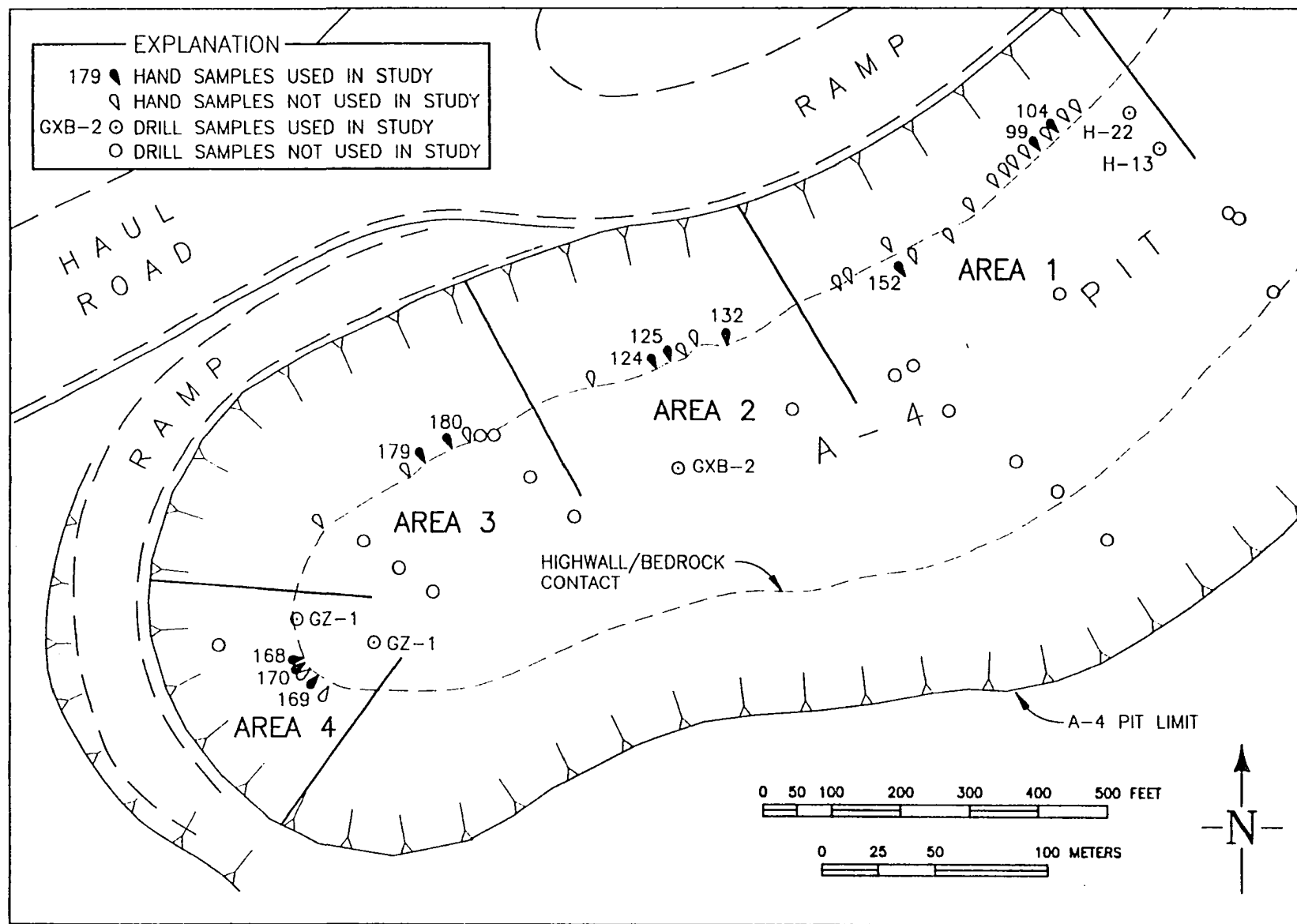


Figure 10-1 Drill study sample locations.

Table 10-1 Basic statistics for +20 mesh gold grains collected by hand.

	WEIGHT (mg)	LENGTH (mm)	WIDTH (mm)	THICK (mm)	CSF	LOG WT
ALL GRAINS						
COUNT	82	82	82	82	82	82
MIN	5.5	1.26	1.19	0.30	0.138	0.74
MAX	1057.9	14.10	7.48	1.90	0.448	3.02
MEAN	99.6	4.09	2.78	0.73	0.227	1.69
STD	176.9	2.06	1.29	0.33	0.069	0.47
AREA 1						
COUNT	25	25	25	25	25	25
MIN	5.5	1.26	1.19	0.30	0.145	0.74
MAX	181.1	5.48	3.61	1.24	0.413	2.26
MEAN	34.5	2.70	2.08	0.57	0.247	1.37
STD	36.3	0.99	0.61	0.20	0.069	0.37
AREA 2						
COUNT	25	25	25	25	25	25
MIN	16.7	2.44	1.55	0.42	0.139	1.22
MAX	1057.9	9.98	6.11	1.90	0.314	3.02
MEAN	119.1	4.71	3.12	0.77	0.202	1.82
STD	205.0	1.62	1.17	0.38	0.058	0.41
AREA 3						
COUNT	15	15	15	15	15	15
MIN	16.6	1.82	1.48	0.48	0.156	1.22
MAX	721.5	14.10	6.45	1.49	0.448	2.86
MEAN	164.3	4.54	3.28	0.88	0.258	1.90
STD	201.6	3.06	1.68	0.32	0.082	0.53
AREA 4						
COUNT	17	17	17	17	17	17
MIN	18.6	3.19	1.59	0.39	0.138	1.27
MAX	905.2	9.39	7.48	1.81	0.305	2.96
MEAN	109.5	4.84	2.87	0.75	0.206	1.77
STD	202.0	1.66	1.34	0.33	0.050	0.39

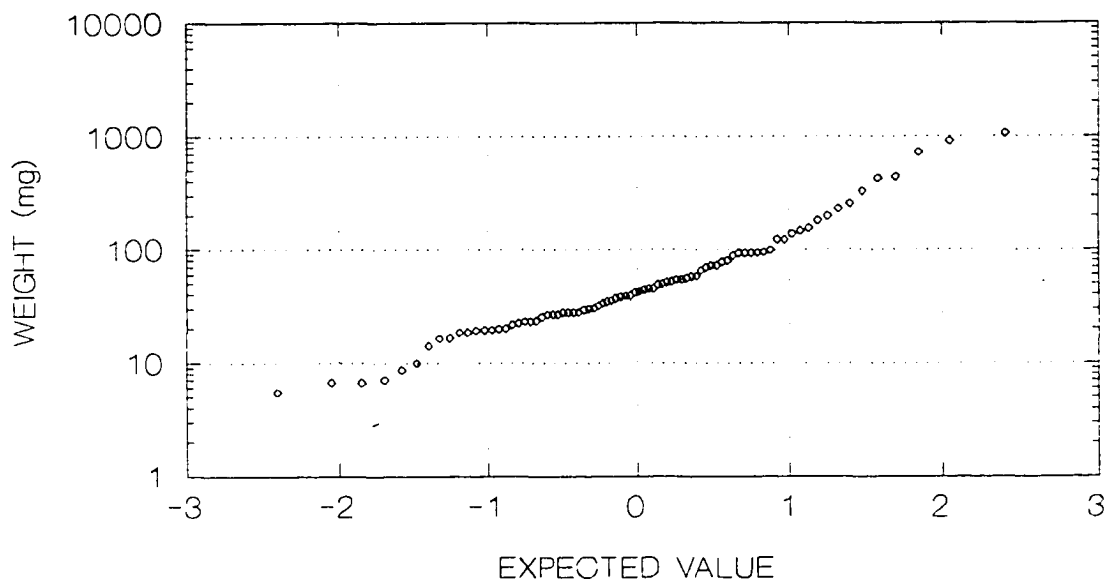


Figure 10-2 Log-probability plot of grain weight for gold grains collected by hand.

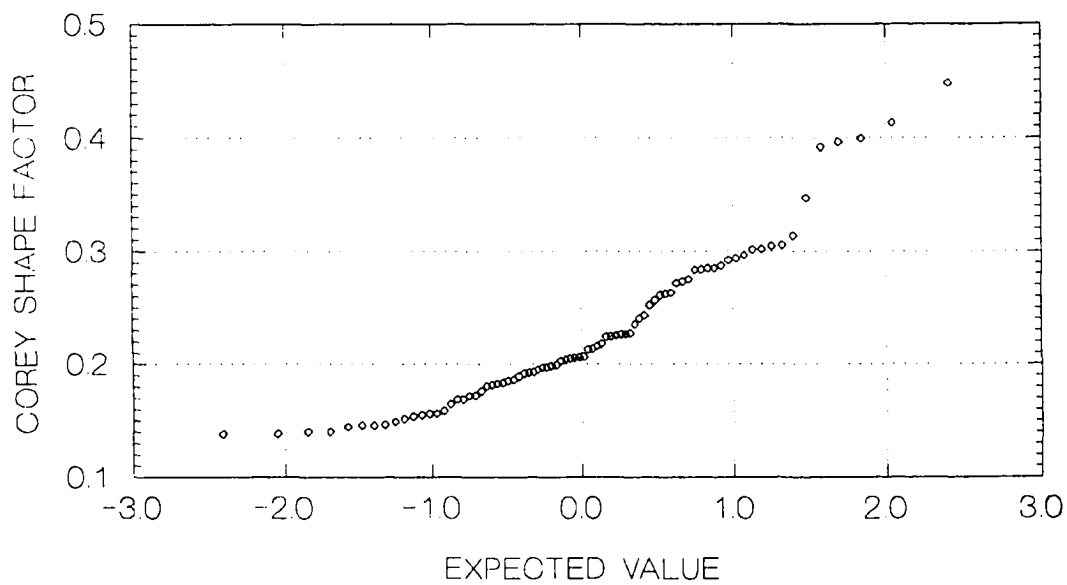


Figure 10-3 Probability plot of CSF of gold grains collected by hand.

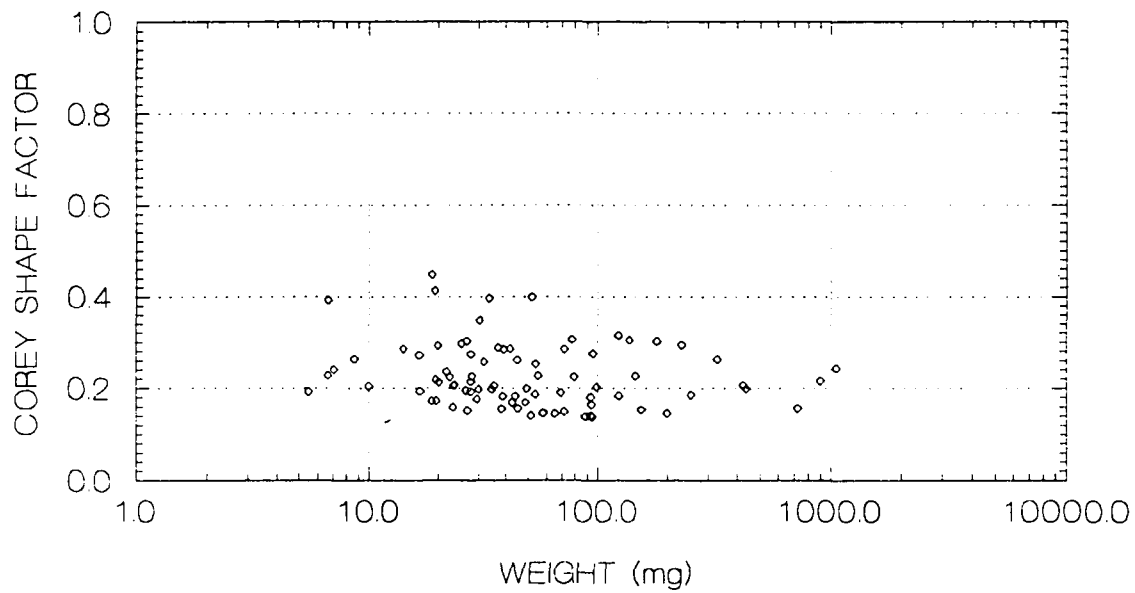


Figure 10-4 Corey shape factor relative to log weight for grains collected by hand.

samples were available from Area 3. A maximum of 10 grains were selected from each sample by the random techniques outlined in the previous chapter.

The descriptive statistics for the 32 grains are presented in Table; the raw data are in Appendix I. The weight of the 32 grains is lognormally distributed, and the CSF is normally distributed (Figure 10-5 and Figure 10-6, respectively). A scatter plot of CSF versus log weight (Figure 10-7) shows that there is a small variance in CSF, a high variance in log weight, and that CSF is independent of log weight (correlation coefficient is 0.232). All grains are flat (mean CSF of 0.253), regardless of their weight (geometric mean weight of 19.5 mg).

Table 10-2 Basic statistics for +20 mesh gold grains from drill samples.

	WEIGHT (mg)	LENGTH (mm)	WIDTH (mm)	THICK (mm)	CSF	LOG WT
ALL GRAINS						
COUNT	32	32	32	32	32	32
MINIMUM	4.1	1.38	1.12	0.23	0.130	0.61
MAXIMUM	937.3	5.53	3.28	1.43	0.467	1.93
MEAN	30.2	2.77	2.07	0.61	0.253	1.29
STD	26.8	0.95	0.68	0.29	0.081	0.43
AREA 1						
COUNT	11	11	11	11	11	11
MINIMUM	4.1	1.92	1.13	0.23	0.130	0.61
MAXIMUM	937.3	3.03	2.19	0.62	0.241	1.41
MEAN	36.7	3.03	2.19	0.62	0.241	1.41
STD	30.6	0.76	0.64	0.25	0.073	0.39
AREA 2						
COUNT	9	9	9	9	9	9
MINIMUM	8.3	1.40	1.36	0.33	0.165	0.92
MAXIMUM	66.0	3.76	3.28	1.43	0.467	1.82
MEAN	33.1	2.76	2.36	0.69	0.277	1.42
STD	19.4	0.75	0.68	0.32	0.104	0.32
AREA 4						
COUNT	12	12	12	12	12	12
MINIMUM	22.2	2.53	1.75	0.53	0.247	1.09
MAXIMUM	4.4	1.38	1.12	0.24	0.145	0.64
MEAN	25.9	1.15	0.59	0.27	0.063	0.45
STD	670.5	1.33	0.34	0.07	0.004	0.20

Again, the areas used for the random stratified sampling were used as a grouping variable in ANOVAs. Testing log weight and CSF, the results of these ANOVAs (Table 10-3) indicate that there is no difference between the means of the 3 areas at the 95% confidence level.

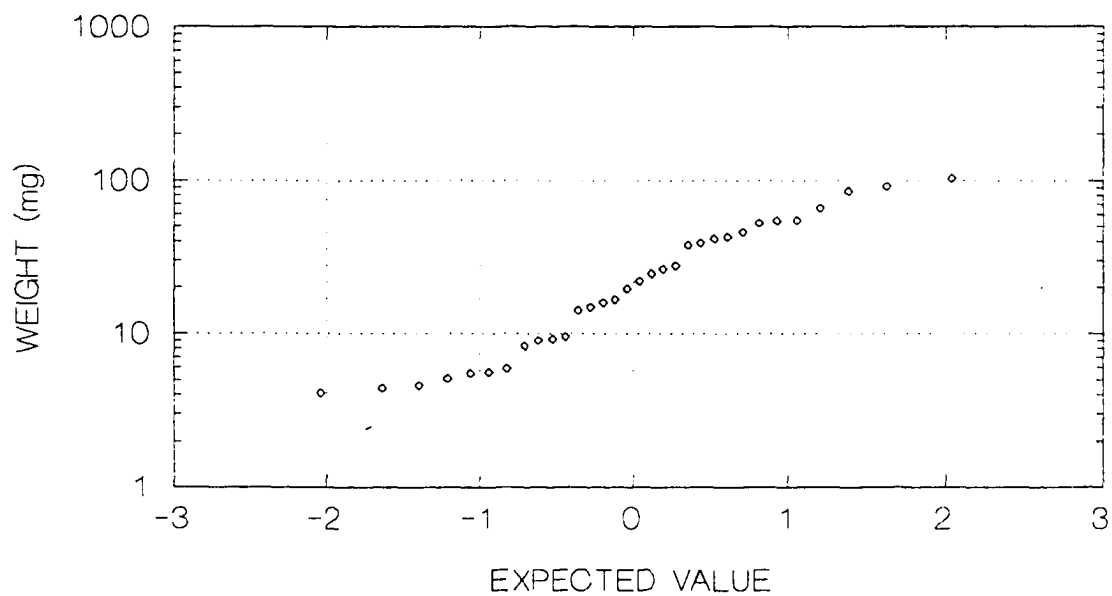


Figure 10-5 Log -probability plot of grain weight for gold grains collected by drilling.

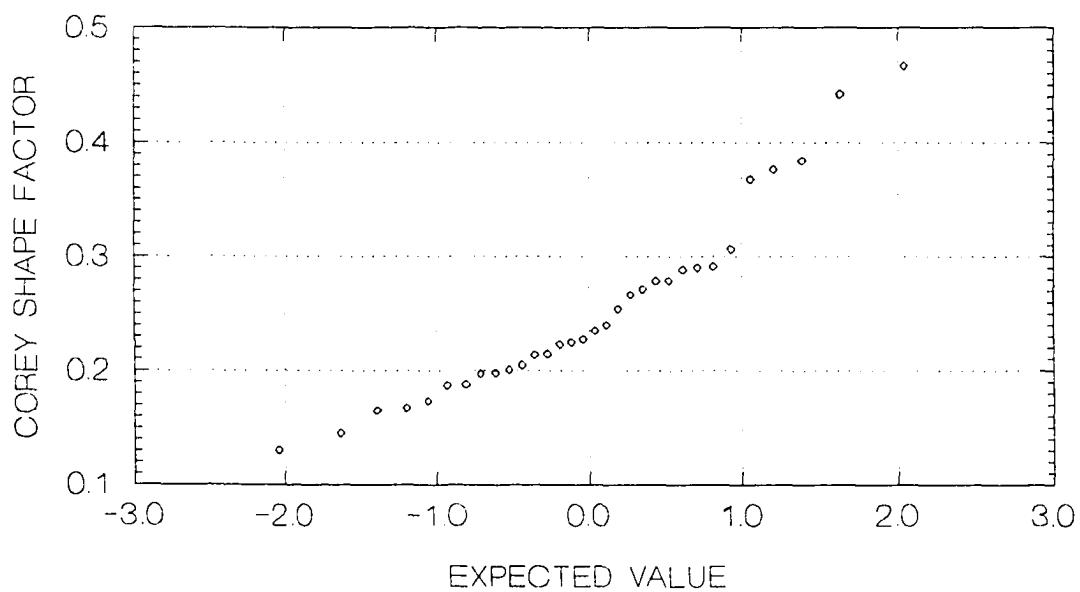


Figure 10-6 Probability plot of CSF of gold grains collected by drilling.

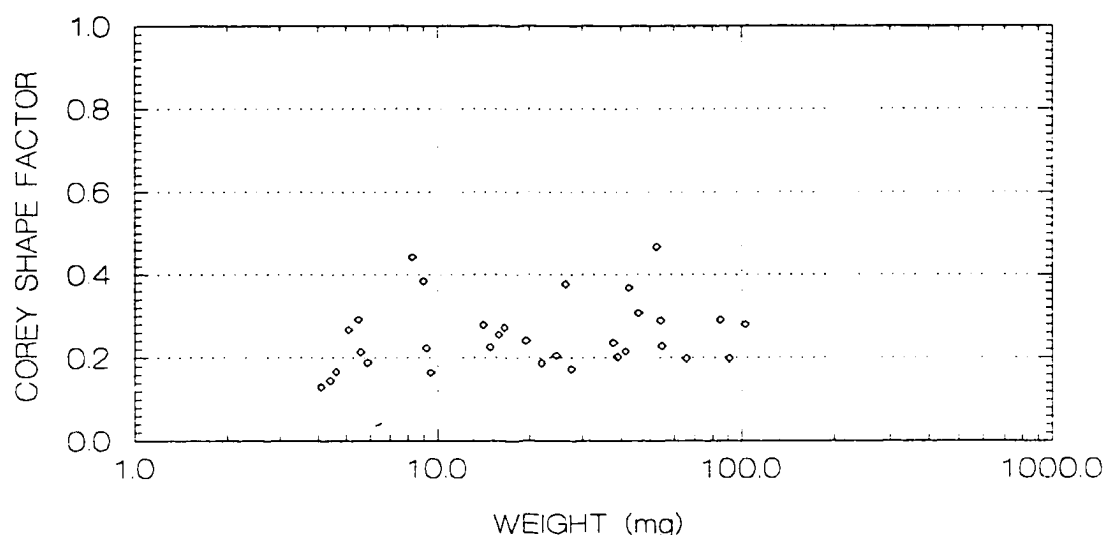


Figure 10-7 Corey shape factor relative to log weight for grains from drill samples.

Table 10-3 Drilling recovery ANOVA results.

Null hypothesis: For the given area, the mean CSF or log weight of the population of +20 gold grains collected by hand is equal to the mean CSF or log weight of the population collected by drilling.

Alternative: For the given area, the mean CSF or log weight of the population of +20 gold grains collected by hand is not equal to the mean of the population collected by drilling.

Reject null hypothesis and accept the alternative at a probability equal to or less than 0.05.

Area	Log Weight			CSF		
	D.F.	F	Probability	D.F.	F	Probability
All	1, 112	16.948	0.000	1, 112	2.910	0.091
1	1, 34	0.074	0.788	1, 34	0.064	0.802
2	1, 32	6.554	0.015	1, 32	6.543	0.015
4	1, 27	17.922	0.000	1, 27	3.411	0.076

D.F. = Degrees of Freedom

F = F statistic

10.6. COMPARISON OF DRILL AND GRAB/CHANNEL SAMPLES

To test the equivalence of the two populations, it is first necessary to establish that the variances are equivalent. Only if the variances are equivalent is it appropriate to test the equivalence of means. Using the F test, the variances of the two populations are equivalent for both CSF and log weight at the 95% confidence level. To test the equivalence of the means of the

two areas, the t test was used. The critical t value is 1.98 for a 5% significance level and 112 degrees of freedom. The computed t statistic, comparing the mean CSF, is 1.67. Since this is less than 1.98, the mean CSFs are equivalent at the 95% confidence level. However, the t statistic for the log weight is 4.20 (absolute value of -4.20). This value is greater than the critical value of 1.98; therefore, the geometric mean weights are significantly different. These results are shown graphically in Figure 10-8 and Figure 10-9. The mean weight of the two populations is also shown in Table 10-4.

The +20 gold grains from drilling typically weigh at least 50% less than the +20 gold grains recovered with a shovel by hand from the same area. Reverse circulation drilling is apparently much more efficient at recovering light gold grains than heavy grains, but the shape of the grain (within the range considered) does not affect gold recovery. This can be seen in a scatter plot of CSF versus log weight for the 2 sample populations (Figure 10-10).

The equivalencies of the 3 areas that are common to the two sample populations were also compared using the F test (equivalence of variance) and t test (equivalence of means). The results of these tests are shown in Table 10-5.

There is no difference between the two sample populations in Area 1 at the 95% confidence level for either variable, as shown in the scatter plot in Figure 10-11. This is the area that formed a different subpopulation in the hand collected samples because of the significantly smaller mean weight. Apparently then, reverse circulation drilling will give accurate results if the mean weight of the population is sufficiently low.

The results for Area 4 are straightforward and fit the pattern that has emerged. The CSF between the two populations is not different, but the weight is (Table 10-5 and Figure 10-12). Area 4 is part of the coarser grained subpopulation of the hand collected samples. Again, reverse circulation drilling does a poor job of producing a representative sample in an area with coarse gold.

The results for Area 2 are quite different. The two populations are significantly different in both weight and CSF (Table 10-5 and Figure 10-13). The weight of the grains has equivalent variance, but the means are not equal. The CSF of the two populations is different based on unequal variance at the 95% confidence level. This is probably because of two outliers which

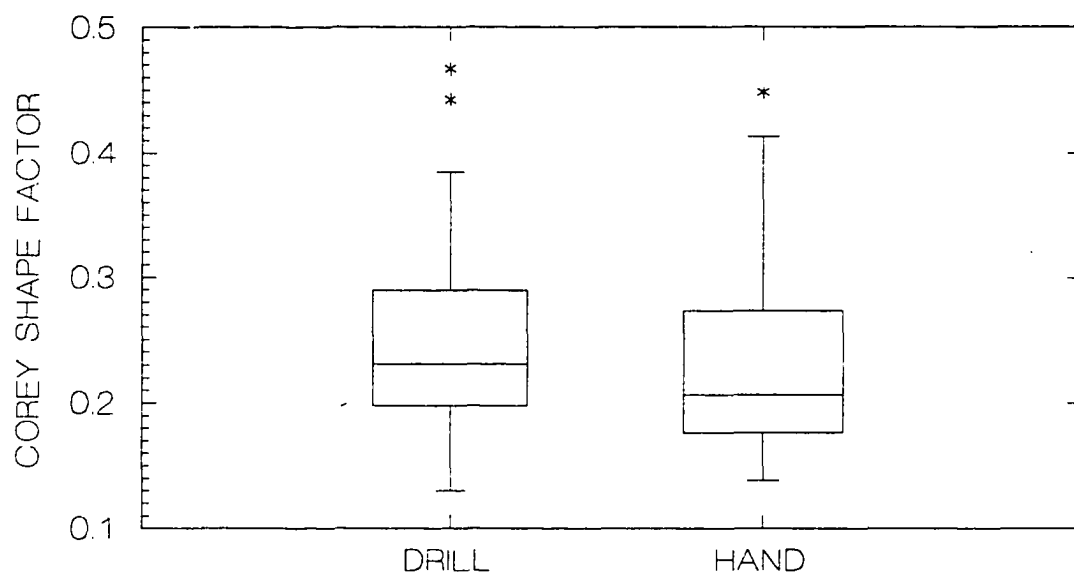


Figure 10-8 Box plots comparing CSF of grains collected by hand and by drilling.

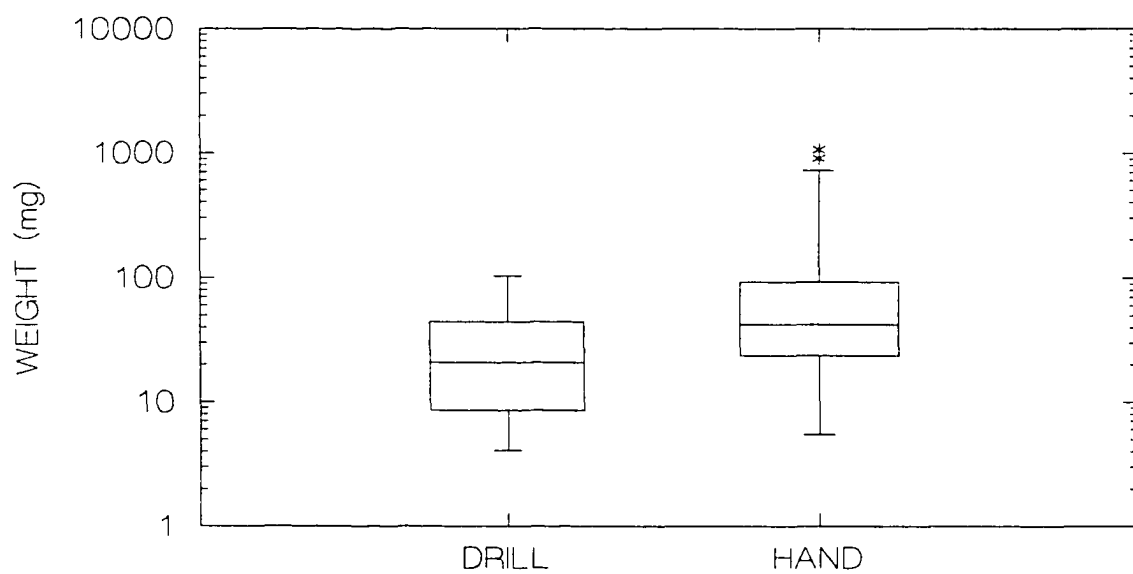


Figure 10-9 Box plots comparing log weight distribution of grains collected by hand and by drilling.

Table 10-4 Weight difference between +20 mesh gold grains collected by hand and by drilling.

Population	Log Weight		Weight (mg)	
	Mean	Median	Mean	Median
Hand	1.69	1.62	49.0	41.7
Drilling	1.29	1.28	19.5	19.1
Difference (mg)			-29.5	-22.6
Difference (%)			-60.2%	-54.2%

Geometric mean and median are reported under "Weight."

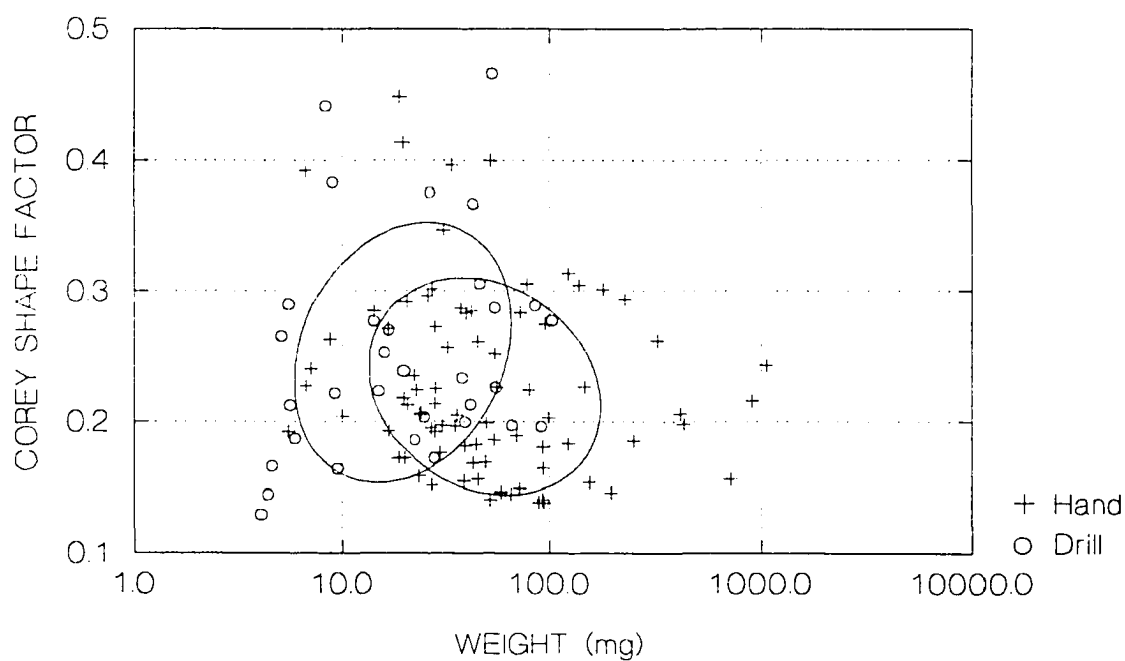


Figure 10-10 Semi-log plot comparing gold grains collected by hand and by drilling--entire population. 50% of the given population will fall within the ellipse.

Table 10-5 Comparison of the subareas using F and t statistics.

Null hypothesis: There is no difference in CSF or weight between samples collected by hand and samples collected by drilling for a given area.

Alternative: For a given area, the variance of the CSF of samples collected by hand and collected by drilling is different; for a given area, the variance of the weight of samples collected by hand and collected by drilling is different

Reject null hypothesis and accept the alternative at a probability equal to or less than 0.05.

TYPE	F				t		
	D.F.		STAT	PROBABILITY	D.F.	STAT	PROBABILITY
AREA 1							
CSF	24	10	1.00	0.529	34	0.23	0.819
WEIGHT	24	10	1.07	0.480	34	0.29	0.774
AREA 2							
CSF	24	8	3.23	0.045	32	na	na
WEIGHT	24	8	1.70	0.222	32	2.63	0.013
AREA 4							
CSF	16	11	1.33	0.321	27	1.86	0.074
WEIGHT	16	11	1.33	0.321	27	4.37	0.000

na = t statistic not applicable because of unequal variance.

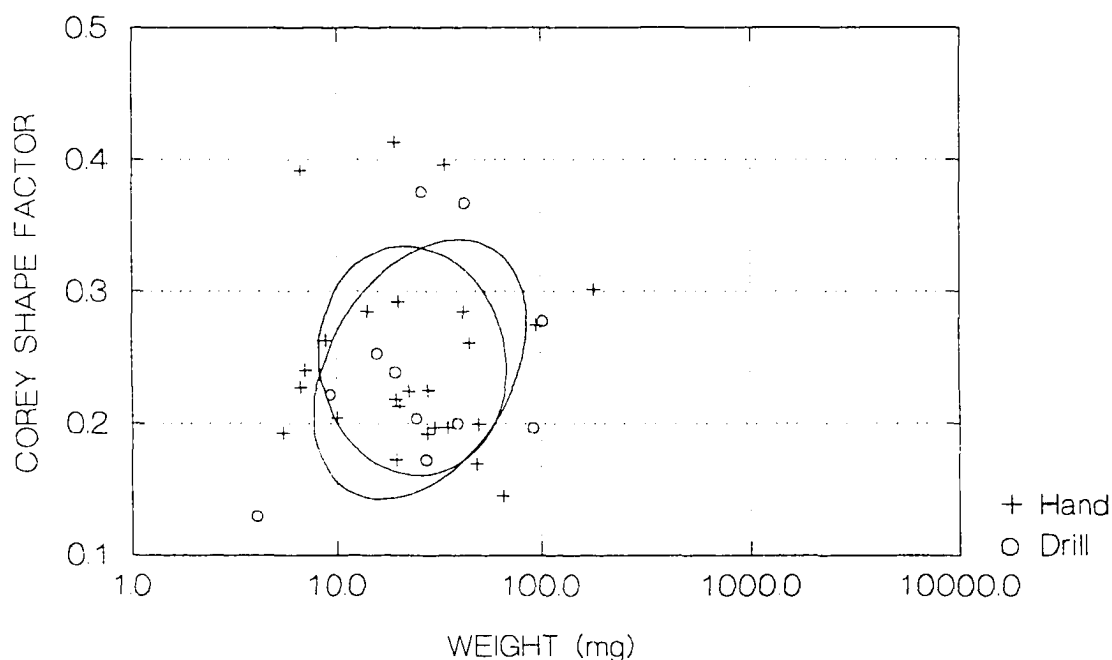


Figure 10-11 Semi-log plot comparing gold grains collected by hand and by drilling--Area 1.

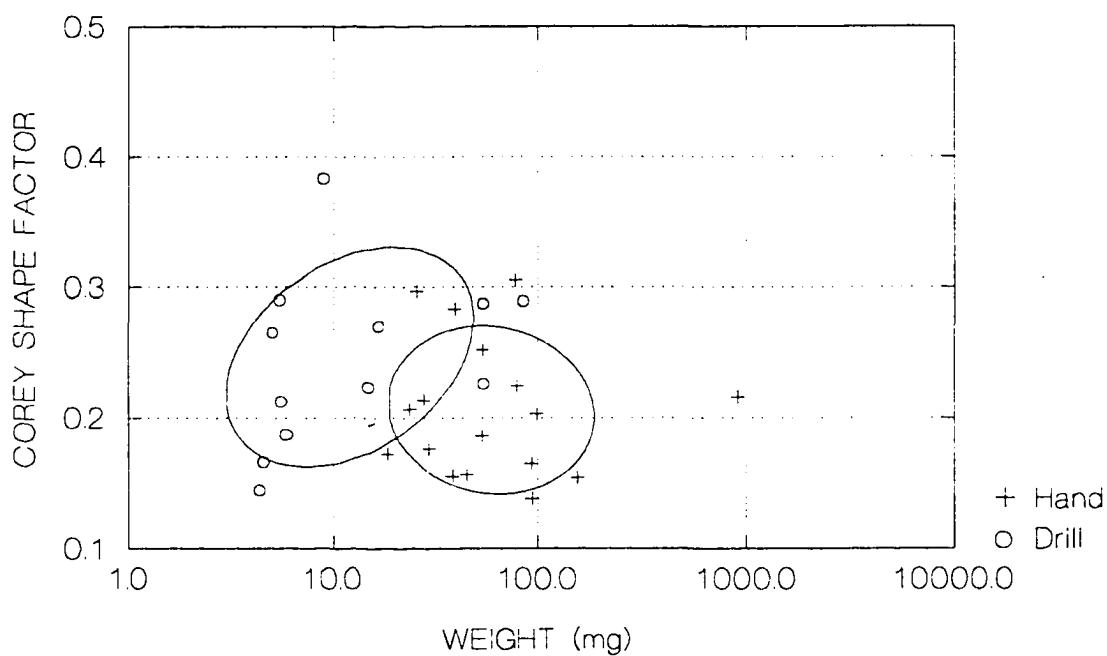


Figure 10-12 Semi-log plot comparing gold grains collected by hand and by drilling--Area 4.

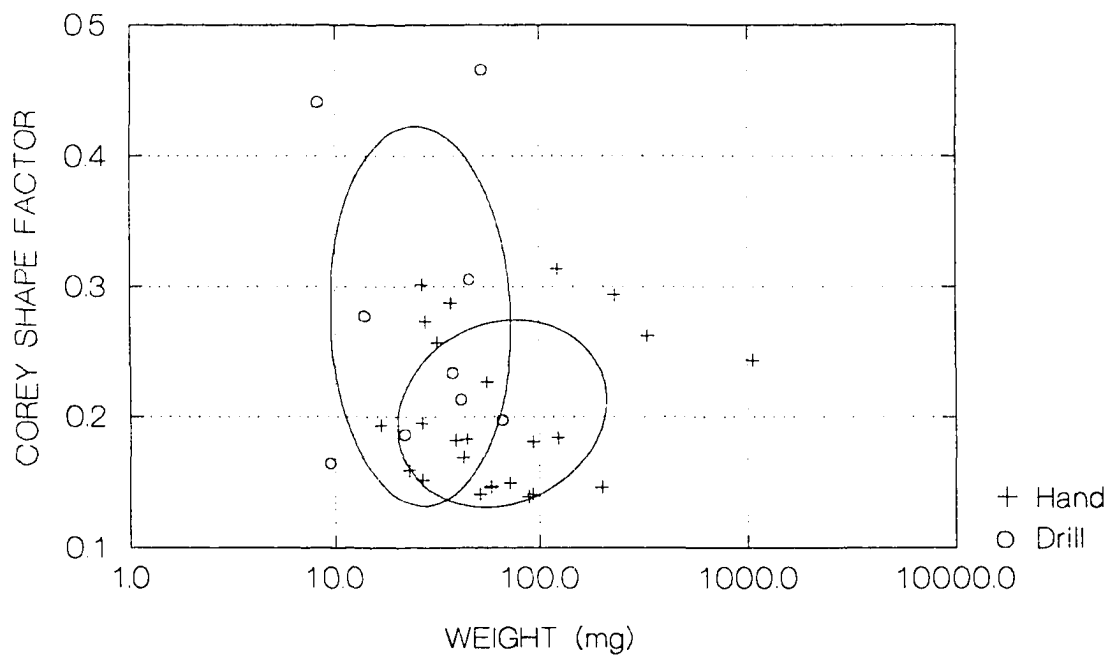


Figure 10-13 Semi-log plot comparing gold grains collected by hand and by drilling--Area 2.

cause the variance of the drill population to be high (Figure 10-13). Since this is the only time in the entire drill study that the CSF of the drilled gold grains is different from that of the hand collected samples, I suggest the results are a function of the small number of grains and the two outliers. Most likely, if there were more grains in the drill sample population for this area, the CSF would prove not to be different. The significant difference in weight between the drill and hand collected samples fits the pattern for large gold grains. Reverse circulation drilling seems to do a poorer job of producing a representative sample in areas with coarse gold grains.

10.7. DISCUSSION

This study indicates that there is a significant difference between the sample population of gold recovered in drilling and the sample population recovered in the pit by hand. These results are based on a sufficiently large number of grains to be reliable. Even though statistical tests put numbers on the significance of results, a subjective interpretation is required to decide whether or not the number of observations is sufficient, in light of the variability of the population. The smaller population, 32 observations, is adequate; this is demonstrated by the relatively smooth slope on the cumulative frequency curves of the drill data. On the other hand, these grains are drawn from only 5 samples (effectively only 4, since one sample had only one +20 grain). Subdividing the sample population into 3 areas with an average of 11 grains each is probably shaky. The variability in placer samples is known to be rather high (one of the major problems in ore reserve calculations). I think the number of observations in each sample population is adequate. Though the number of observations in each area is less than ideal, the consistent results (with one exception) suggest that conclusions drawn from the area breakdown of the sample populations are probably valid.

I think it is important to note that though this chapter is a study of the quality of samples collected by reverse circulation drilling, it is not an indictment of reverse circulation drilling. There are problems with all of the methods currently in use for drilling placer deposits. It is my opinion that churn drilling, the industry standard, produces worse results than reverse circulation drilling. Churn drills make a hole by pounding the gravel, cobbles, and boulders into little pieces. In a wet hole, which most are, what happens to the gold during this process? The bottom of the hole is an agitated slurry of water and sediment, and the gold grains settle to the bottom of this slurry just as

they do in a stream during a flood event. When the pounding stops and the sediment is bailed out of the hole, the gold is at the bottom, where it is difficult to collect, rather than distributed through the sediment. These results indicate that in any situation where the economics of a deposit require an accurate assessment of the ore reserves, the quality of the drill samples should be investigated, as they have been here. The drilling method can then be modified in an attempt to produce better results, or should this fail, steps can be taken to account for the problem in the calculation of the ore reserves. It is important to realize this early. In the case of reverse circulation drilling at the Valdez Creek deposit, the grade of each sample should be adjusted by a factor that is a function of the size distribution of the gold in the sample. This cannot be done if size data have not been collected.

10.8. SUMMARY

It has been shown that samples collected by reverse circulation drilling are systematically biased with respect to grade control samples that were collected by hand. The latter are thought to be more representative of the gold as it occurs naturally in the ground that is being sampled. Gold grains in samples that were collected by reverse circulation drilling have an average weight that is less than 50% of the weight of gold grains collected by hand. The bias appears to occur only above a certain average weight, so that this is more of a problem in areas with coarser grained (heavier) gold than in areas with fine grained gold. It has also been shown here that the shape of the gold grain is not a function of the sampling method, at least within the range of CSF considered here. There is no difference in shape between the gold collected by hand and the gold collected by drilling.

These results indicate that weight or any variables that are highly correlated with weight are dependent upon the sampling method and should not be used in the statistical tests in the next part of this study. However, if one assumes that all samples collected by the same method (reverse circulation drilling) are equally biased, then samples collected by that method can be compared to each other. In other words, samples collected by hand and by reverse circulation drilling are not biased based on their shape and can be compared regardless of the way they were collected, but the samples are biased by the collection method in regard to weight, and only samples collected by the same method may be compared to each other using weight and correlated variables.

11. GRAIN SIZE

11.1. INTRODUCTION

Grain size, expressed as weight, is certainly one of the variables that is of most interest to a mining company. Unfortunately, drilling does not uniformly recover all weights of gold grains. As a result, gold recovered by different methods cannot validly be compared.

The gold used in this study has been recovered by two methods. The majority of the gold is from the Valdez Creek Mine and was recovered by reverse circulation drilling. The gold from White Creek was also recovered by reverse circulation drilling, but the gold from Lucky Gulch was recovered by hand digging. Therefore, the weight of the gold grains can be used only if the data set is restricted to the Valdez Creek Mine (A Channel, A Bench, Tammany Channel, B-Pl Channel), or to Valdez Creek Mine (VCM) plus White Creek.

The other size variables that were measured include length, width, and thickness. If they show a high correlation with weight, they are suspect and have a restriction to their use similar to that for weight.

11.2. MEASUREMENT

Weight was measured on a typical laboratory digital scale with an accuracy of 0.1 mg. Length and width measurements were made using a dial micrometer with an accuracy to 0.01 mm while viewing the gold grains under a variable power light microscope. The thickness was measured by noting the distance between the bottom and top focal plane. Least projection dimensions (Folk, 1974) were recorded.

Duplicate measurements of all four variables were made on ten grains. ANOVAs for each variable indicate that measurement errors are not a concern. For each of the four variables, the probability that all grains are equal based on the duplicate measures is 0.000.

11.3. BASIC STATISTICS

The correlation of the four variables is shown in Figure 11-1. The correlations of the length, width, and thickness with weight are all significant at $\alpha < 0.05$. The significant

correlation of these variables with weight indicates that these variables cannot be used in analyses comparing all six channels. However, analyses using these variables are valid if restricted to the four Valdez Creek Mine channels, because these samples were all collected by reverse circulation drilling and therefore are all subject to the same bias.

The basic statistics describing the size parameters (VCM only) can be found in Table 11-1. Weight, length, width, and thickness have log-normal distributions. Figure 11-1 includes CSF also. Since length, width, and thickness are correlated with weight, and CSF is a function of these three variables, the possible correlation of CSF with weight must be considered. The correlation between weight and CSF is $R = -0.124$, which is not significant ($n = 29$).

11.4. RESULTS AND DISCUSSION

Size is a difficult parameter to interpret, because it is the result of many factors. Size is initially controlled by the size distribution of the gold in the bedrock source area or areas. In the surficial environment, the average size of gold grains has been found to decrease with increasing distance from the source (Giusti, 1986; Gorshkov *et al.*, 1971). This is probably a result of the typically concave stream profile, with high energy environments near the head of the stream and progressively lower energy toward the mouth. However, the size of gold grains in any particular segment of a stream is highly variable because the size is ultimately controlled by the depositional environment.

Transport distance is not used as a variable in this study because the source or sources of the gold are not known. Transport distance is potentially a factor in the multivariate distribution of the grains, but when looking at the grains just from the Valdez Creek Mine, it probably is not significant because the grains were collected in roughly the same area and the distance between sample sites is small relative to the distance from the probable source area(s). Glacial transport, however, may significantly complicate the transport picture, since a grain carried in glacial ice has received a “free ride” and its size may be affected very little even though it has been transported a large distance.

Figure 11-2 shows box-plots of weight, length, width, and thickness grouped by channel (Valdez Creek Mine only). ANOVAs indicate that there are no significant differences between the

geometric mean weight, length, and width of the gold from each channel at the 0.05 significance level. This lack of significance is a result of high within-channel variance, which can be attributed to the many factors controlling the size distribution.

Thickness, unlike the other three size variables, does show a significant difference between channels. The ANOVA results in an F-ratio of 3.923, with 3 and 25 degrees of freedom, for a probability of 0.020. Grain thickness seems to be an intermediate variable between size and shape.

Thickness has a correlation with weight of 0.695 and a correlation with CSF of 0.547, both of which are significant at $\alpha < 0.05$. This dual correlation is probably due in large part to the uniformly flat character of the gold grains at Valdez Creek. Both the weight and CSF are sensitive to small changes in thickness.

Table 11-1 Basics statistics for the size variables--VCM only.

	WEIGHT (mg)	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)
Distribution	log	log	log	log
No. of cases	29	29	29	29
Minimum	1.50	1.15	0.70	0.18
Maximum	116.68	4.28	3.52	1.69
Mean	16.75	2.49	1.74	0.45
-1 STD	5.97	1.71	1.15	0.30
+1 STD	46.99	3.63	2.63	0.69

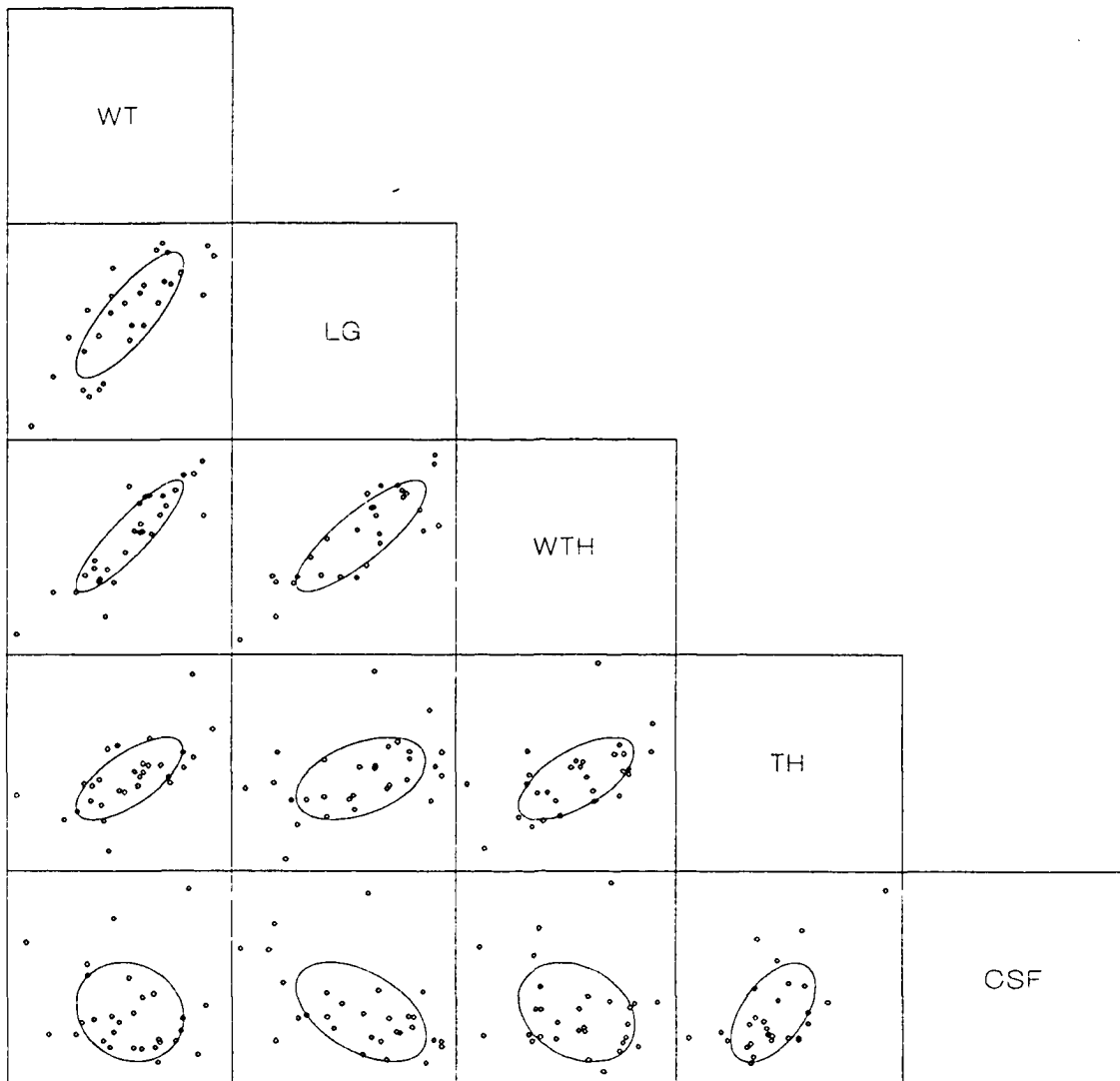


Figure 11-1 Scatter plot matrix of weight, length, width, thickness, and Corey shape factor (CSF). Data are standard normal; 50% of the populations should fall within the ellipses assuming they are bivariate normal. Narrow ellipses indicate high correlation between variables; more circular ellipses indicate poor correlation.

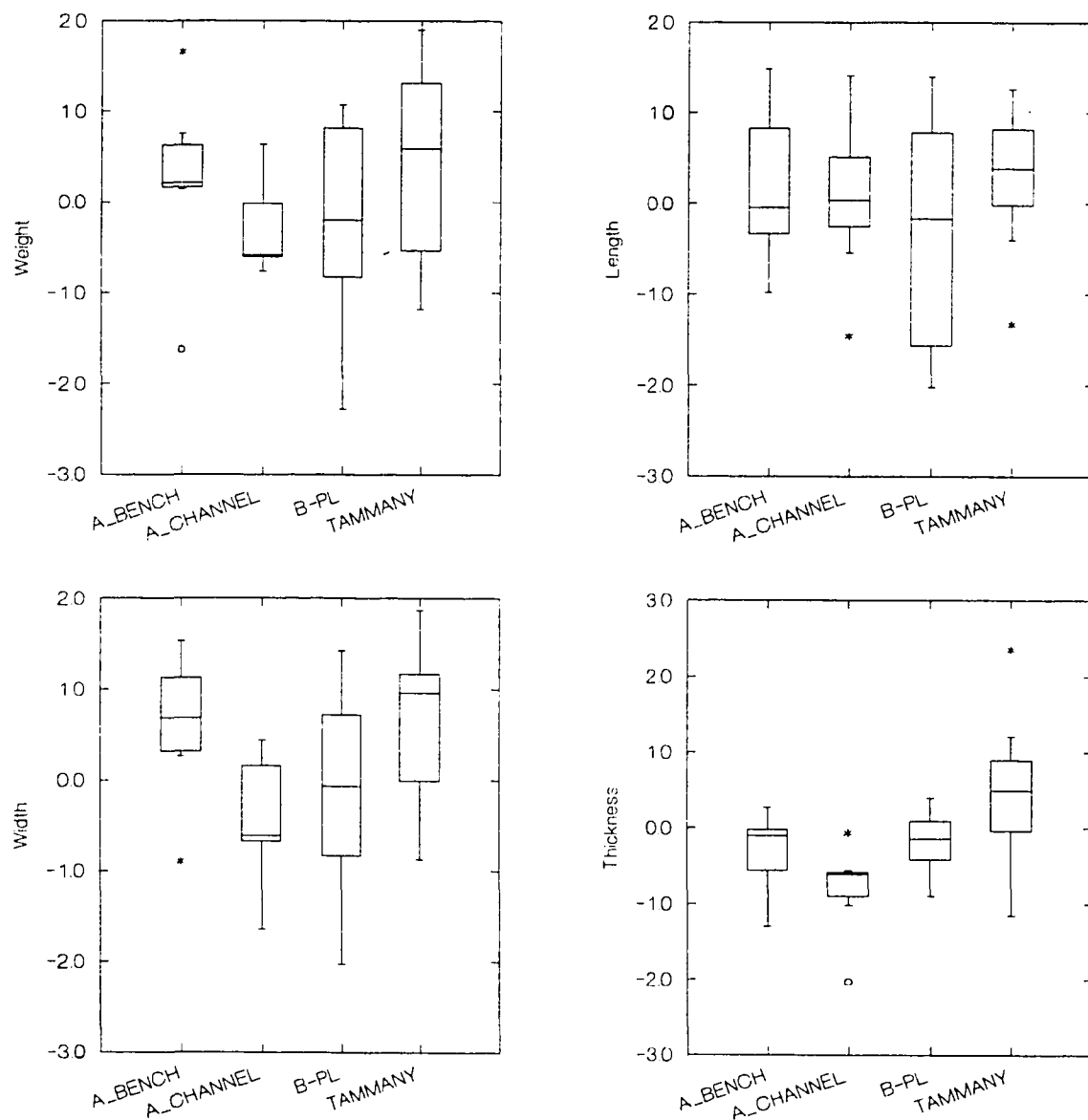


Figure 11-2 Box plots showing distribution of weight, length, width, and thickness by channel--VCM only. Data are standard normal.

12. GRAIN SHAPE

12.1. INTRODUCTION

One of the hypotheses tested in the drill recovery study was that gold recovery by reverse circulation drilling might be affected by grain shape. The Corey shape factor (CSF) was used as the measure of shape, specifically sphericity. The study showed no significant difference in CSF between gold grains collected by hand and those collected from drill samples in the same area of the deposit. These results indicate that CSF can be used as a variable in comparing samples from all areas where samples were collected in the Valdez Creek drainage.

Shape, like size, is inherited from the bedrock source and is modified during transport. The shape is also influenced by the transport mechanism, in this case glacial or alluvial. Four shape variables have been evaluated in this study: CSF, rounding, sphericity, and regularity. Each is influenced differently by the many factors that shape a placer gold grain.

CSF is a quantitative measure of sphericity. Sphericity was also estimated by ranking the grains on an arbitrary scale ranging from 1 to 5, with 1 being more flat and 5 being more spherical. The range of this scale is the range for grains in the Valdez Creek drainage, which tend to be flat, and therefore is not representative of other deposits. Rounding was also estimated by ranking the grains on a scale of 1 to 5. The scale is equivalent to that of Powers (1953). However, I find it more convenient to have the integer value represent the center of a class rather than the division between classes. Thus, 1 = angular, 2 = sub-angular, 3 = sub-rounded, 4 = rounded, and 5 = well rounded. Very angular grains were not observed in the grains collected in the Valdez Creek drainage.

One additional shape variable was found to be useful in describing gold grains. Gold does not necessarily inherit a compact shape from its bedrock source, and actually may be quite irregular with numerous protrusions and embayments. Also, because gold is both highly malleable and ductile, the inherited irregularities of a gold grain will evolve differently than those of a silicate grain. The “regularity” of the gold grains was ranked from 1 to 5, with 1 very irregular (numerous protrusions and embayments) and 5 being very regular (no protrusions or embayments). Ideally,

this scale is independent of rounding and sphericity: both a cube and a sphere are very regular; a child's "jacks" (the little things with spines that they pick up while tossing a ball) are extremely irregular but are spherical and well rounded.

12.2. RESULTS

Duplicate measurements were made on ten grains to evaluate the reproducibility of the measurements of each variable. As in the previous chapter, an ANOVA was used to compare the variance between duplicate measurements of a single grain to the variance between grains. For each three variables--sphericity, CSF, and regularity--the variance between duplicate measurements of a grain is sufficiently less than the variance between grains that there is less than a 5% chance that the grains are the same; therefore, a single measurement of each grain is sufficient to describe these three variables. However, there is greater than a 5% chance that the 10 grains have the same mean rounding. Error in estimating rounding is too high to rely on a single measurement; therefore, the available data are insufficient for rounding to be used in this study.

The useful shape variables were found to be best approximated by the following distributions:

CSF:	lognormal
sphericity:	lognormal
regularity:	normal

The population distributions are shown in Figure 12-1, and the population parameters are shown in Table 12-1. CSF does not normalize well (Figure 12-1), but a log transformation gives the best results and is used. The correlation of the shape variables with one another is shown in Figure 12-2. Only one of these correlations, that of CSF and sphericity at $R = 0.835$, is significant, with a less than 5% probability that the correlation could occur by chance. An ANOVA of the CSF results grouped by source indicates that there is less than a 5% probability that the six sources have the same mean CSF. Figure 12-3 shows box plots of CSF by source (all data in the box plots have been normalized and standardized). The A Channel and A Bench have the flattest grains, with little variation. Lucky Gulch is at the other extreme, with the least flat grains. The White Creek results are consistent with qualitative observation of a bimodal population of mostly moderately flat grains, with a smaller population of very flat grains similar in

character to those in the main Valdez Creek paleochannels. The large variance in the B-PI CSF was not noted while measuring. As expected, sphericity shows a similar distribution by source (Figure 12-3) and similar ANOVA results (the coincidence of the median and hinge point is due to the discontinuous, categorical nature of the data).

The regularity of the grains when grouped by source also shows significant results, with a less than 5% chance that the sources have the same means. The box plots of regularity by source (Figure 12-3) are somewhat difficult to interpret because of the categorical nature of the data, but it is apparent that Lucky Gulch and White Creek are less regular than the Valdez Creek paleochannels. A surprising result is that the A Channel has the least regular grains of the Valdez Creek paleochannels, while the A Bench is the most regular.

12.3. DISCUSSION

Classically, sedimentary particles are expected to become more spherical and rounded with transport distance. This wisdom is derived from the study of silicate particles. An additional variable describing the character of gold grains, regularity, has been employed here. Silicates show variation in the degree of regularity as defined here, but since it is of less importance, it is part of the difference between angular and well rounded grains. Thus, in silicates, regularity also increases with transport distance.

The grains from Lucky Gulch and White Creek were collected relatively near their bedrock source compared to those from the A Bench, A Channel, B-PL Channel, and the Tammany Channel. The CSF of the gold grains from these channels suggests flatter grains with increased transport distance. This probably reflects the transporting medium. All of the grains available for this study, with the possible exception of the Lucky Gulch grains, have potentially experienced glacial transport. The data might suggest that gold grains become more flat with increased glacial transport distance.

Regularity shows a pattern similar to that of CSF and sphericity, with grains from channels proximal to potential source areas being less regular than the grains from channels relatively distal to bedrock sources. An increase in regularity would seem expectable regardless of the transport medium. The difference in regularity between the A Bench and the A Channel, two

sources that should have similar relative transport distances, is an enigma that suggests that there are other factors controlling the degree of regularity besides transport distance.

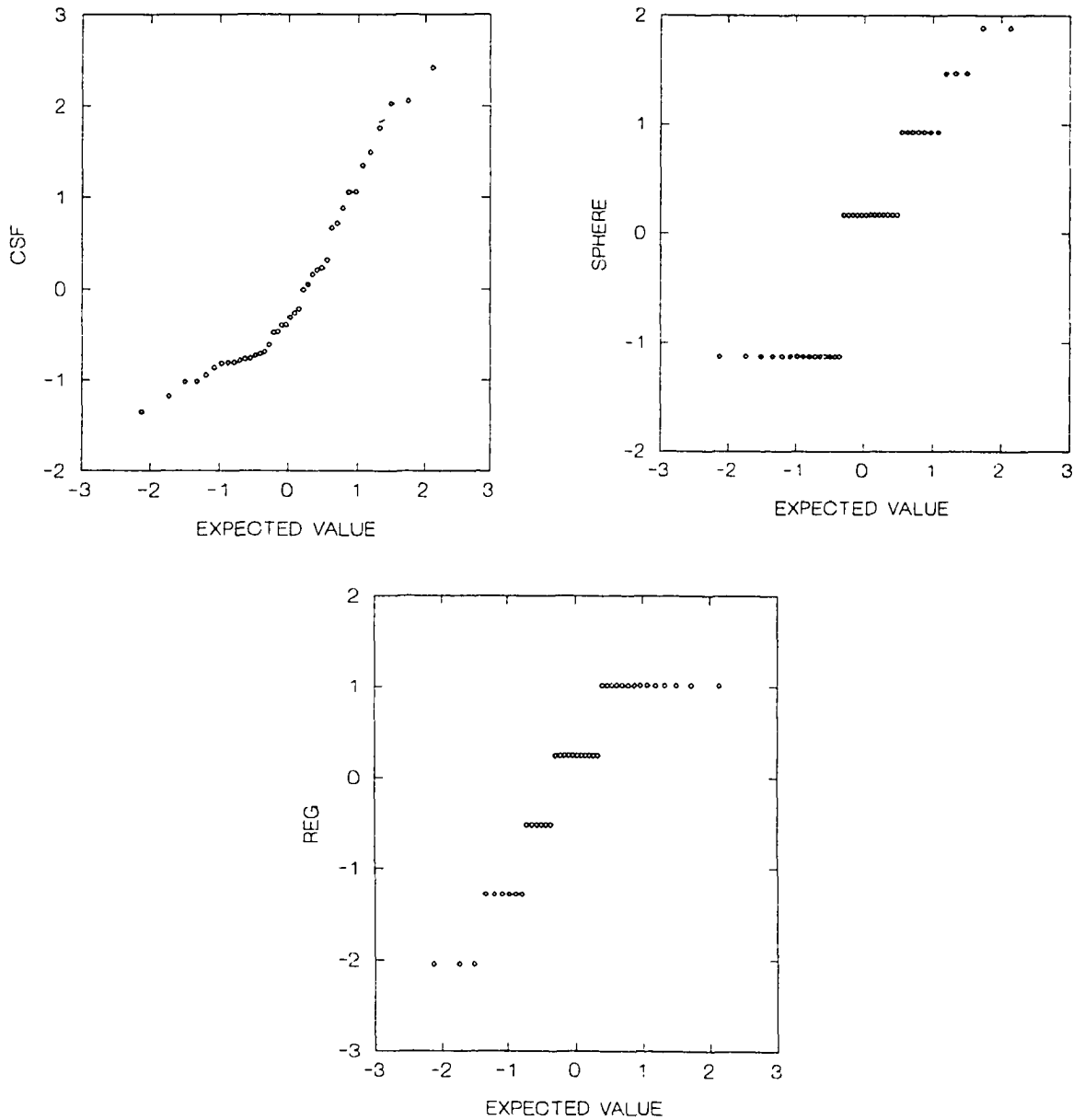


Figure 12-1 Probability plots of CSF, sphericity, and regularity. Data are standard normal.

Table 12-1 Basic statistics for CSF, sphericity, and regularity.

	CSF	REG	SPHERE
Distribution	log	normal	log
No. of cases	40	40	40
Minimum	0.132	1	1
Maximum	0.818	5	5
Mean	0.254	4	2
-1 STD	0.156	2	1
+1 STD	0.412	5	3

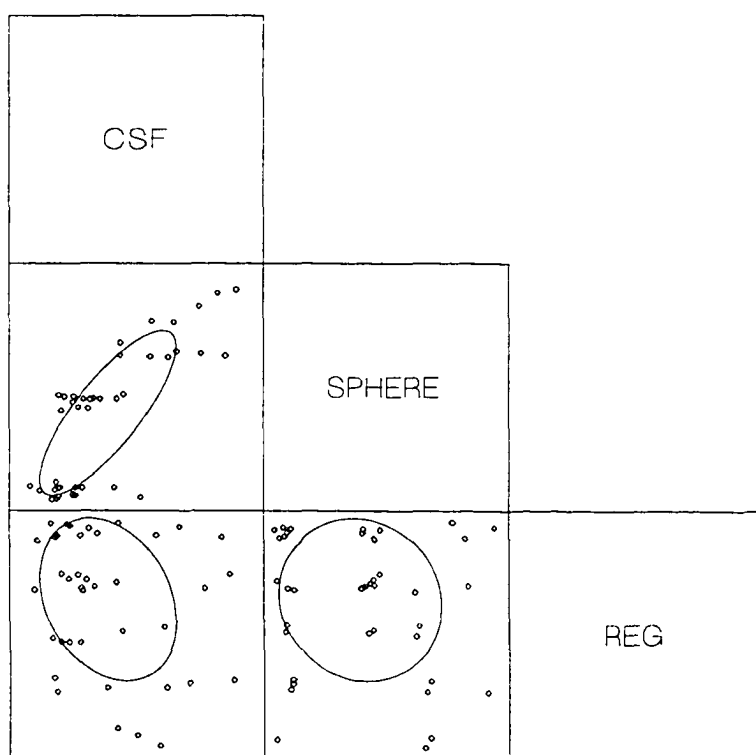


Figure 12-2 Scatter plot matrix showing correlation of CSF, sphericity, and regularity (standard-normal data).

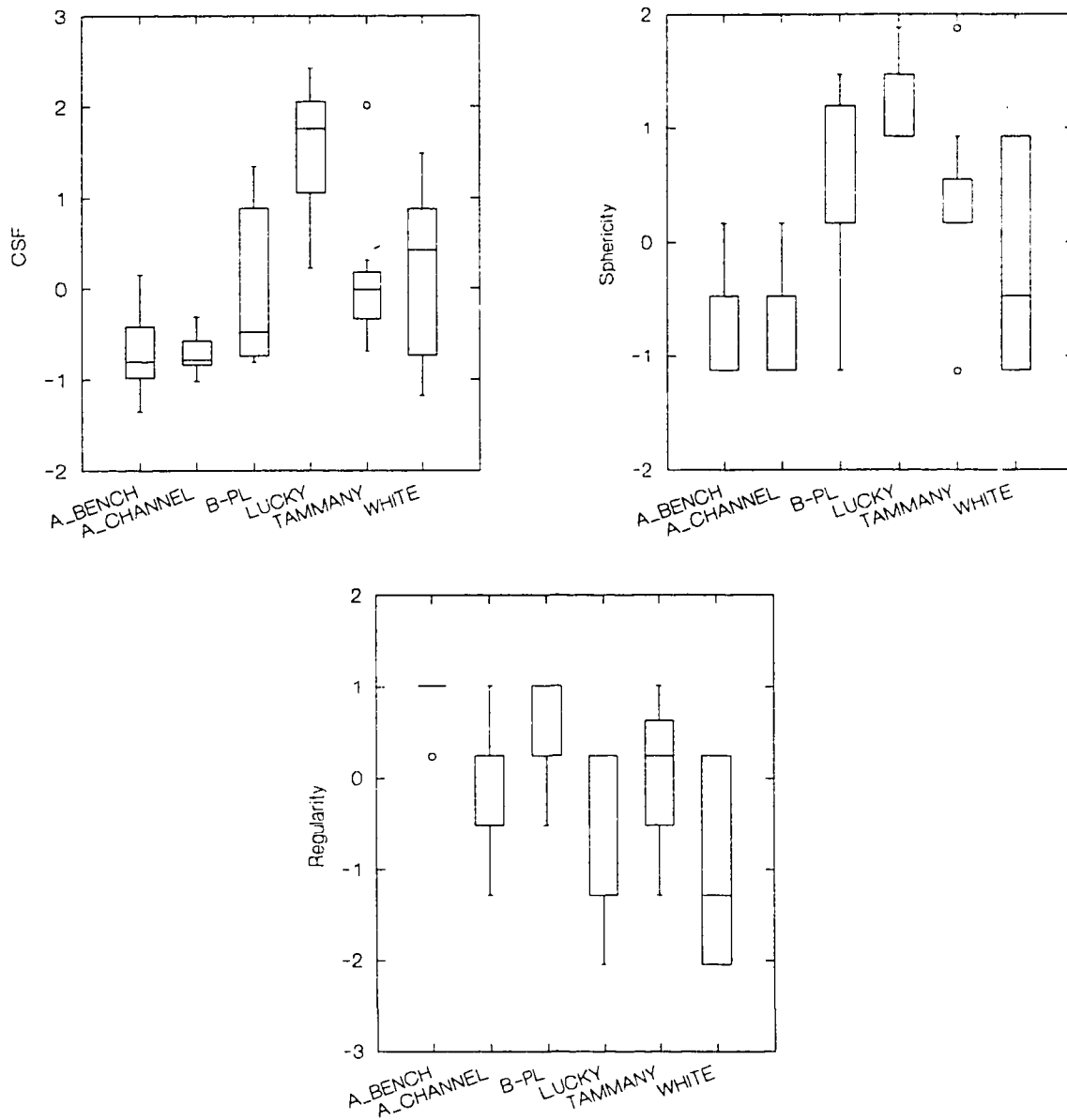


Figure 12-3 Box plots by channel of CSF, sphericity, and regularity. Data are standard normal.

13. GOLD GRAIN SURFACE MORPHOLOGY

13.1. INTRODUCTION

This chapter focuses on the morphology of the surface of the gold grains. Surface features can be grouped into four general categories based on genesis: inherited, mechanical, corrosion, and precipitation.

13.2. INHERITED

Inherited features include features that are intrinsic to gold grains when viewed at high magnification and remnant features that originate at or before liberation of the gold grain from the enclosing rock.

A stepped appearance to a grain surface is the most obvious inherited feature when viewed at moderately high magnification. The steps are crystal growth planes (Moffatt *et al.*, 1964). Stepping is present on grains from Valdez Creek, but is partially to almost completely obscured because of secondary modification (Figure 13-1).

Crystal casts are occasionally found on the gold grain surfaces. The casts are the imprints of minerals such as quartz or pyrite that were originally attached to the gold grain. The casts are generally recognizable as a geometric shaped imprint on the grain. At Valdez Creek, the casts are often further distinguished by their relative lack of secondary modification.

Cavities are another feature classified here as inherited. Cavities probably derive from a number of processes. Some cavities are probably the result of small irregular mineral or rock inclusions that have weathered out of the grain (similar to above, but without distinct form). Others probably are the remains of spaces between gold dendrites or other irregular protrusions that were smashed into more compact shapes during transport by water and glacial ice. Still others probably result from the folding or rolling of sheet-like gold into a more compact shape during transport. It is also possible that some of the cavities result from the accretion of two or more gold grains, but no evidence for this was recognized on grains from the study area.

No attempt was made to quantify the inherited features on the grain surfaces for this study.

13.3. OVERGROWTHS

Evidence for the precipitation of gold from aqueous solution onto gold grains has been reported in a number of studies (Giusti, 1986; Groen *et al.*, 1987; Clough and Craw, 1989). No evidence of gold overgrowths were seen on grains collected from the Valdez Creek study area.

13.4. MECHANICAL DEFORMATION

Two kinds of mechanical deformation are seen on the surface of the gold grains. These are rolled edges and scratches (Figure 13-2). There is a wide range in sizes of scrapes. The large scrapes are often striated and probably formed during glacial transport (Figure 13-3). Interestingly, the larger scraped areas often have inverted relief (Figure 13-3). The reason for this is unknown.

13.5. CORROSION

13.5.1. INTRODUCTION

Valdez Creek gold can be readily recognized by the flat, regular shape and “frosted” appearance of the grains (Figure 13-2 and Figure 13-4). The “frosted” appearance is due to corrosion. Corrosion is evident in Scanning Electron Microscope (SEM) photomicrographs (400x) by the highly modified, often obscured crystal growth steps and by the numerous etch pits (Figure 13-5). A second contributor to the “frosted” appearance is pitting at a scale visible under a normal light microscope (20x). The coarser pitting may or may not be from corrosion (Figure 13-2).

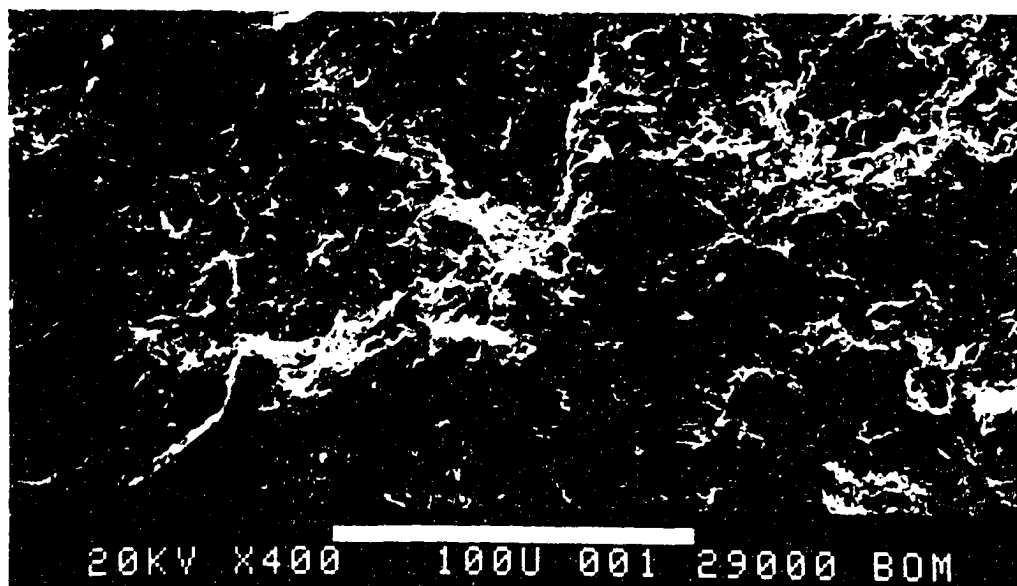


Figure 13-1 Photomicrograph of placer gold grain showing modified crystal growth steps and etch pits. Grain is from the A Channel, 400x magnification, bar-scale is 100 μ m long.

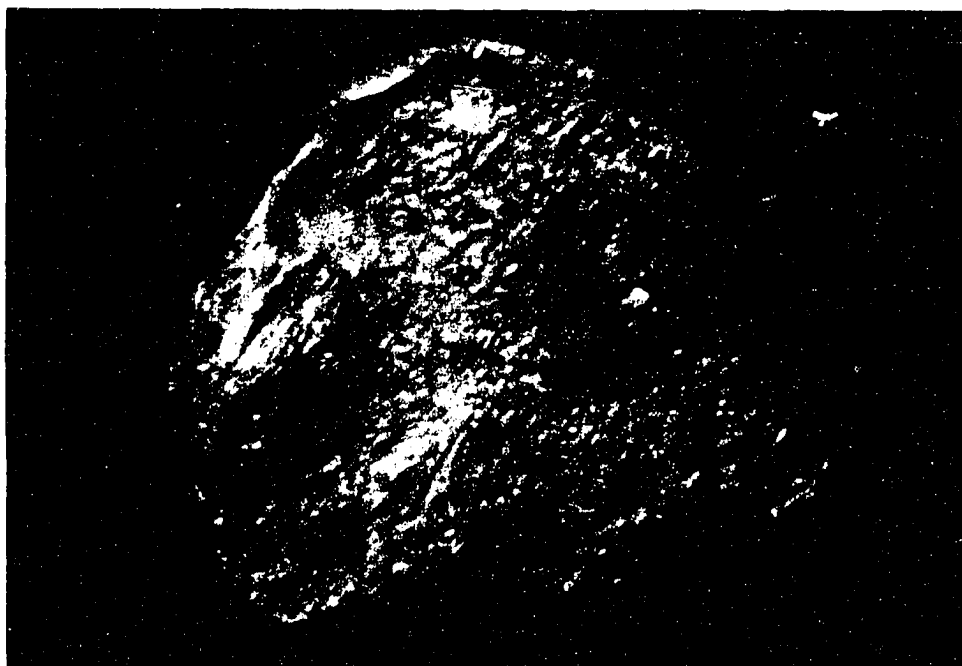


Figure 13-2 Photograph of placer gold grain showing rolled edges, scratches, and "macro" pits which give a frosted appearance (see text for explanation). Grain is 3.0 mm x 2.4 mm and 0.7 mm thick.

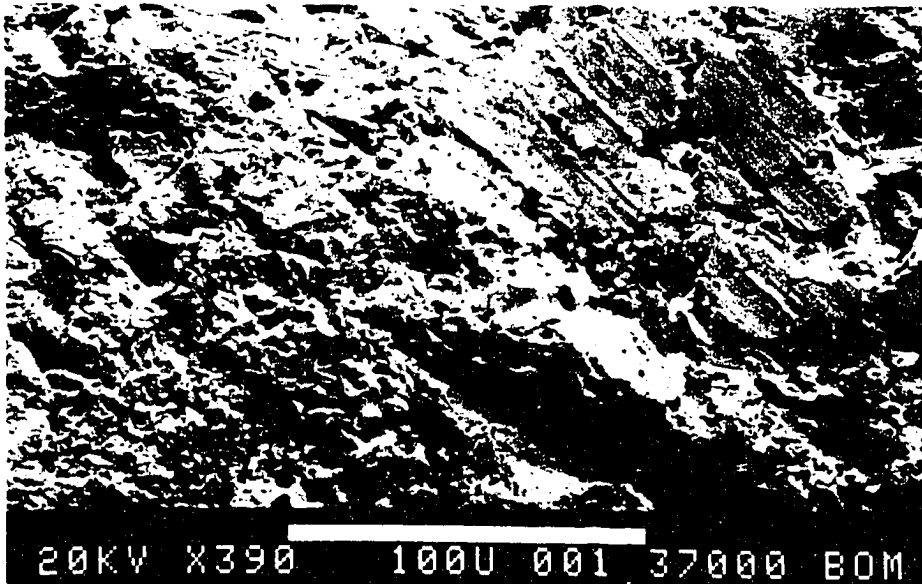


Figure 13-3 Photomicrograph of placer gold grain showing areas with chemical weathering (rough pitted area) and mechanical weathering (smooth area at right center). Smooth striated area possibly formed during glacial transport. Grain is from the A Bench, 390x magnification, bar-scale is 100 μ m long.

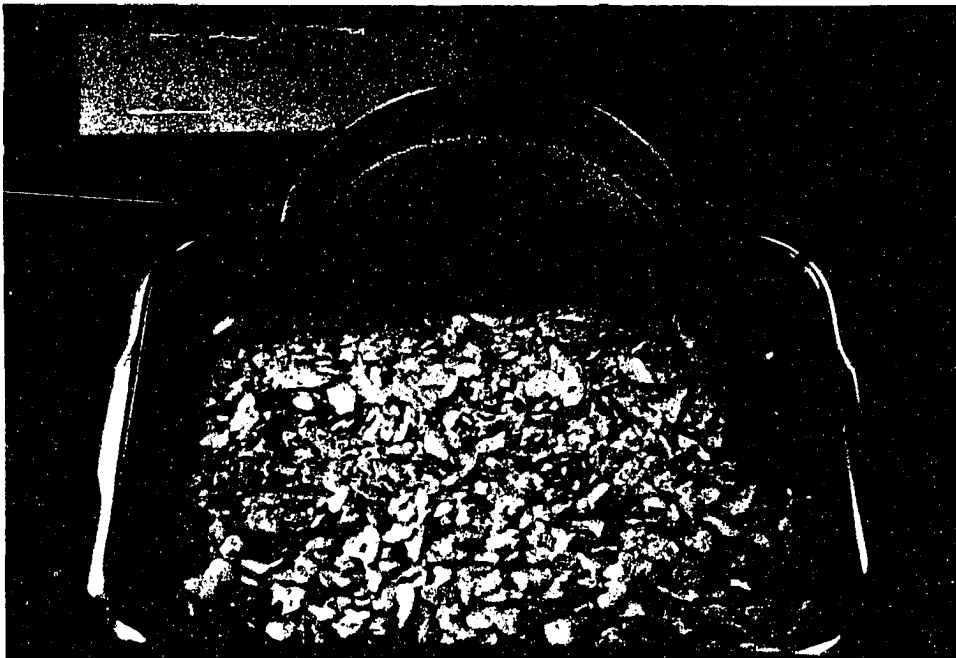


Figure 13-4 Photograph of Valdez Creek Mine coarse gold cleanup. The gold is typically flat and regular in shape.

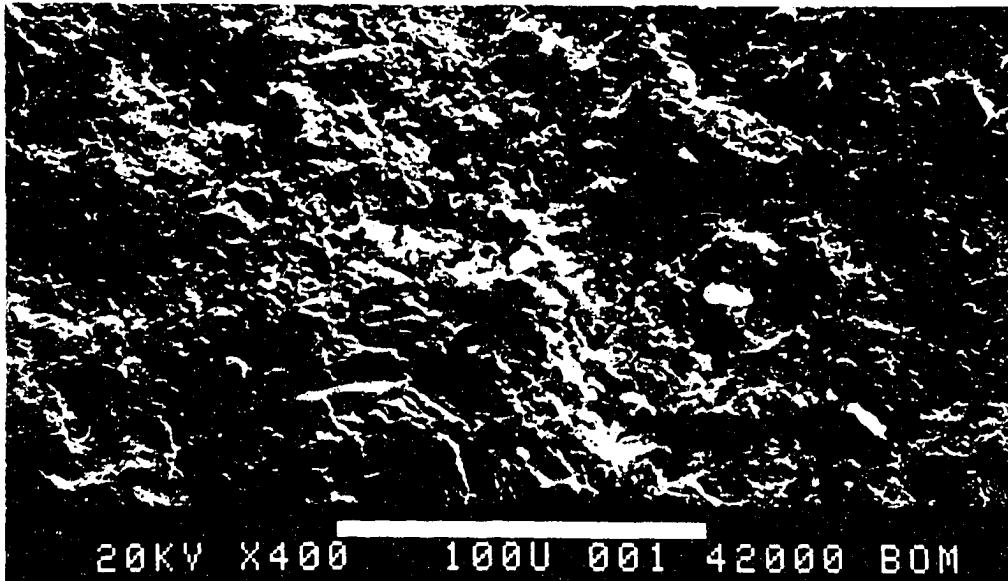


Figure 13-5 Photomicrograph of highly modified placer gold grain showing high density of pitting and almost obscured crystal growth steps. Grain is from the A Bench, 400x magnification, bar-scale is 100 μm long.

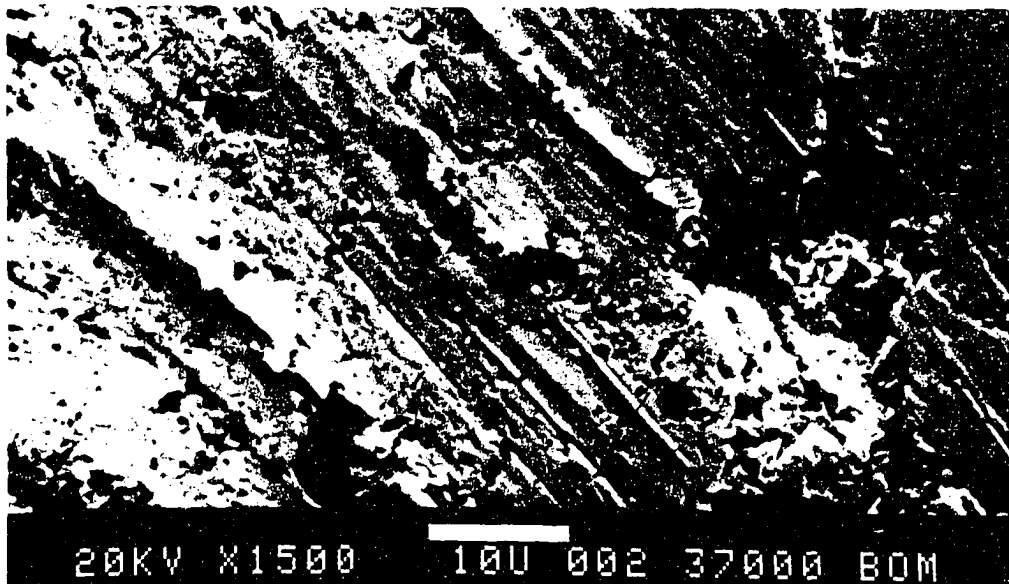


Figure 13-6 Photomicrograph with enlargement of smooth striated area of Figure 13-3 showing development of small etch pits (1500x magnification, bar-scale is 10 μm long).

Corrosion is potentially a significant variable in distinguishing gold grains and their history. The degree of corrosion is an indicator of the amount of chemical weathering that the grain has suffered and therefore may serve as a measure of the length of time the grain has been in the surficial environment. Various measurements of the pitting were evaluated to quantify the degree of corrosion.

13.5.2. FINE PITTING

Fine pitting, as used here, is pitting that is only visible under high magnification. In this study, the fine pitting was investigated using a Scanning Electron Microscope at 400x magnification. Various intensities of fine pitting at 400x magnification can be seen Figure 13-1, Figure 13-3, and Figure 13-5. The shape and size of etch pits are crystallographically controlled in quartz (Brantley *et al.*, 1986). Note that some of the pits in Figure 13-6 are triangular, a shape seen in many minerals, and reasonably expected in gold because of its isometric crystallography.

Images generated with the SEM were analyzed using a Kontron SEM-IPS (image processing system) operated by Arnold Adams of the U.S.B.M., Albany Research Center, Albany Oregon. The number of etch pits in the photomicrograph (400x magnification) and the surface area (in square microns) of each pit were recorded. No attempt was made to measure the depth of each pit.

Both mechanically deformed and corroded surfaces are visible in Figure 13-3, and pitting is evident in each. On most grains, the mechanically deformed part of the surface is a fraction of the corroded surface area. The pits in the mechanically deformed portion of the grain surface are fewer and smaller. This difference in pitting between the corroded and the mechanically deformed parts of the grain is potentially another significant variable in distinguishing the grains. Unfortunately, an insufficient percentage of the grains had enough mechanically deformed surface to provide reliable data. Therefore, the following discussion is restricted to pitting in the corroded portion of the gold grain surfaces.

Pitting proved to be difficult to reliably quantify. A number of different methods were assessed, including average absolute pit size, average pit size at 400x magnification, total pit area, and density of pitting.

13.5.2.1. Absolute Pit Size

A typical probability plot of pit size for one of the grains is shown in Figure 13-7. This is a plot of the $\log(10)$ of pit size, and the reasonably straight line of the upper two-thirds of the plot indicates that the population is log-normally distributed. The flatter-sloped lower third of the plot is the result of lower truncation of the population. A portion of the lower part of the population is missing because the pits were too small to be seen at the magnification employed or are in the size range of the pixels in the photomicrograph ($0.316 \mu^2$) and could not be distinguished. A program for correcting truncation, separating multiple populations, and determining the mean and standard deviation of the resulting population(s) has been developed by Stanley (1987). The pit data for all grains were processed using this program. The modeling indicates that the average truncation of pits in the corroded parts of the grains was approximately 70%. Unfortunately, this extreme truncation produces unreliable results when trying to estimate the other population parameters. It was observed, at higher truncations, that the amount of truncation became more subjective, and the mean and standard deviation were inversely correlated. This observation is borne out by the high negative correlation of $R = -0.893$ between the mean and standard deviation of pit size for the entire population of grains. The absolute size of the pits is not useable as a variable in this study, because of the large lower truncation, but is given in Table 13-1 for guidance in future studies.

13.5.2.2. Size Distribution at 400x Magnification

The possibility of using the subpopulation of pits visible at 400x magnification as a variable was evaluated. The population of pit sizes visible at 400x can be normalized by a log-log transformation (base 10). Figure 13-8 shows box plots of pit size at 400x for eight grains with duplicate analyses. A nested ANOVA for these grains is shown in Table 13-2. The ANOVA indicates that the within-grain variance is too high and therefore any between-grain comparisons are suspect. In order to have reliable data on pit size, multiple areas on each grain have to be analyzed and the resulting average used. Multiple images of each grain were not obtained, except for a limited number of duplicates; therefore, the number of pits visible at 400x cannot be used as a variable in this study.

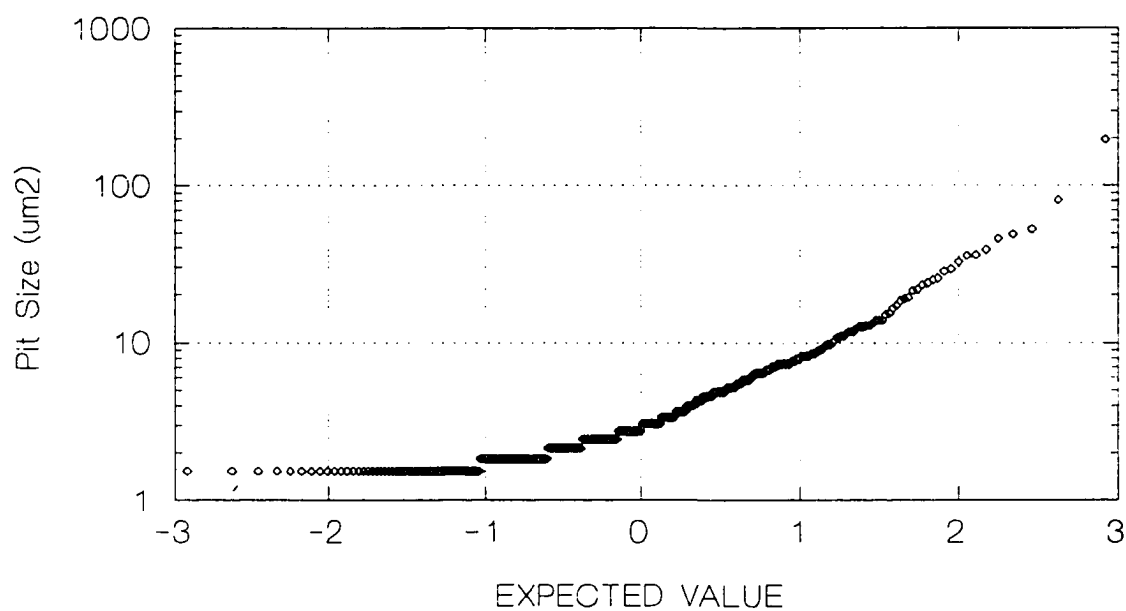


Figure 13-7 Log-probability plot of pit size from typical grain.

Table 13-1 Approximate size (surface area) of corrosion pits in gold grains in the Valdez Creek drainage adjusted for truncation using Proplot (Stanley, 1987).

magnification	400x
mean observed number of pits per grain	259
lower truncation	70 %
geometric mean	0.34 μm^2
-1 standard deviation	0.05 μm^2
+1 standard deviation	2.42 μm^2

13.5.2.3. Total Pit Area

The previous two measurements of pit size are strongly influenced by small pits. Total pit area, defined as the total pit area per 10,000 μm^2 of corroded area, is predominantly influenced by large pits. Even a large number of very small pits makes little contribution to the total pit area; therefore, this measurement is less sensitive to truncation. Since total pit area is influenced by a different size fraction of pit, the within-grain variance may be different than in the previous measurements.

Duplicate measurements on three grains are available for evaluating within-grain versus between-grain variance (due to missing data, the results for 5 of the duplicates could not be normalized to 10,000 μm^2). An ANOVA of pit area, categorized by grain, results in an F-ratio of 0.581 and a probability of the null hypothesis being true (equal grain means) of $P = 0.612$. Therefore, the within-grain variance is too high to permit the use of a single measurement from each grain. Pit area cannot be used as a variable in this study.

13.5.2.4. Density of Pitting

The density of pitting is also dependent on the magnification used. Therefore, the pit density at 400x is different from that at other magnifications, particularly in light of the large amount of lower truncation demonstrated earlier. However, for a constant magnification, pit density is largely independent of pit size, and therefore, might prove useable.

Pit density, defined here as the number of pits visible at 400x per 10,000 μm^2 of corroded surface area, is also subject to high within-grain variance. An ANOVA indicates that pit density, categorized by grain, results in an F-ratio of 0.688 and a probability of $P = 0.568$ that the mean pit density of the grains is equal. Once again, the within-grain variance is too high relative to the between-grain variance to allow the use of measurements taken at a single location on the grain surface.

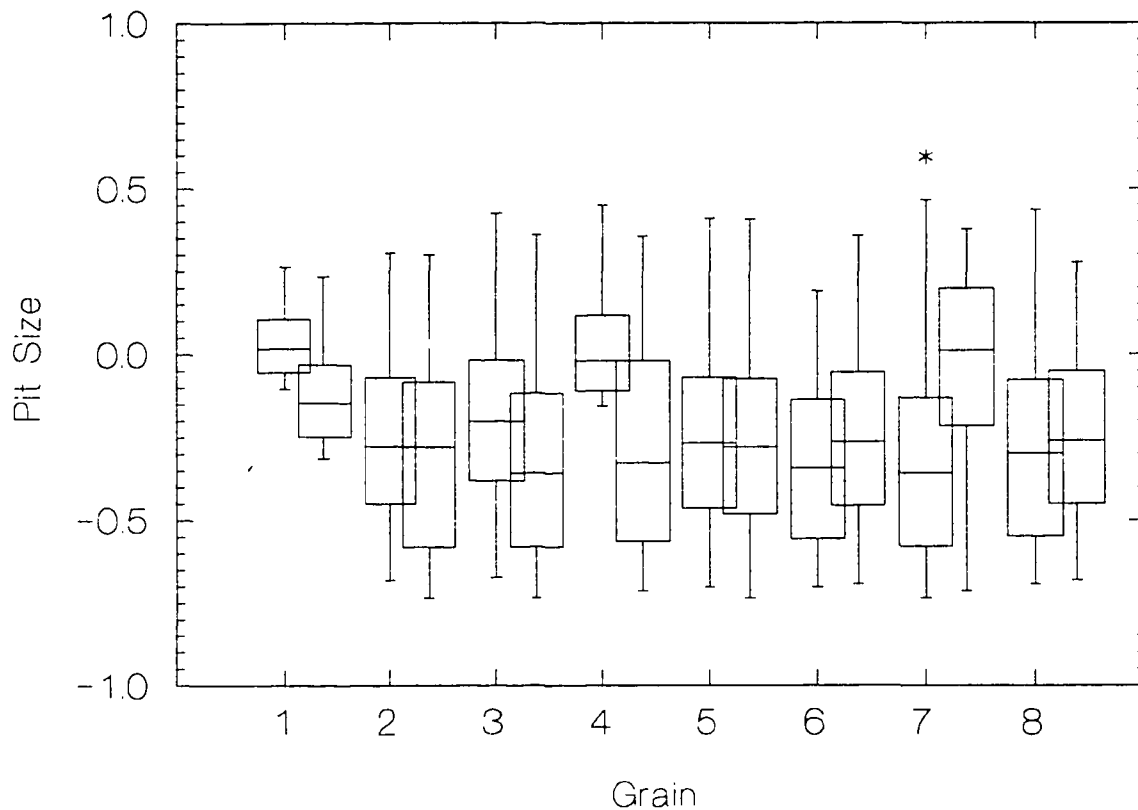


Figure 13-8 Box plots of pit size at 400x for eight grains with duplicate analyses. Data are standard normal.

Table 13-2 Nested ANOVA of pit size at 400x magnification.

Null hypothesis: 1) There is no difference between the mean pit size (surface area of pit) of each grain. 2) There is no difference between the mean pit size of each duplicate sample from a grain.

Alternative: 1) The mean pit size of at least one grain is significantly different than the mean pit size of the other grains. 2) For at least one grain, the mean pit size of one sample of pit sizes is significantly different from the duplicate sample of pit sizes from the same grain.

Criterion: Reject null and accept alternative at a probability equal to or less than 0.05.

SOURCE	SUM-OF-SQUARES	D.F.	MEAN-SQUARE	F-RATIO	PROBABILITY
GRAIN	25.649	7	3.664	55.014	0.000
DUP{GRAIN}	36.929	7	5.276	79.208	0.000
ERROR	315.833	4742	0.067		

dependent variable is $\log(\log(\text{area}))$

Conclusion: The alternative is accepted in both cases.

13.5.2.5. Fine Pitting Summary

Fine pitting has immense potential as a variable in a factorial study such as this. The importance lies in its relative dating potential. The amount of corrosion a gold grain has suffered should be recorded in the intensity of corrosion pitting. Therefore, the intensity of corrosion pitting may have application as a relative dating tool in any area with detrital gold. Unfortunately, this potential was not realized in this study.

This study has documented the existence of micron scale corrosion pits in placer gold grains. It also has been shown that there is a large amount of variation in the intensity of pitting on the surface of an individual gold grain. A number of different measures of the intensity of fine pitting have been evaluated, including absolute pit size, pit size at 400x magnification, total pit area, and density of pitting. Absolute size of the corrosion pits was found to be too small to be reliably evaluated at 400x magnification. The other three measures of pitting intensity were found to be too sensitive to the variability of pitting on the surface of an individual gold grain. The available data are insufficient to evaluate the potential of using fine pitting intensity as a relative dating tool or to use fine pitting as a variable in this study.

13.5.3. LARGE SCALE PITTING

The intensity of pitting visible with a light microscope at 20x was recorded on a relative scale from 1 to 5, with 1 representing very little pitting and 5 representing intense pitting. Intensity, as recorded, is predominantly pit density and subordinately pit size.

An ANOVA of two duplicate measures on ten grains indicates that there is a moderate amount of variance in duplicate observations of a grain, but nonetheless, there is a less than 10% probability that all 10 grains have the same degree of pitting ($F = 2.44$, probability = 0.09). Therefore, estimates of the amount of pitting visible at 20x magnification are sufficiently reproducible to be useful as a variable in the factorial study.

The estimates of large scale pitting are normally distributed, with a mean of 3 and a standard deviation of 1. Box plots of large scale pitting, grouped by source, are shown in Figure 13-9. An ANOVA of large scale pitting by source indicates that at least one source has a significantly different mean from the others when all sources are considered (5 and 34 degrees of

freedom, $F = 2.77$, $P = 0.033$). If the sources are restricted to the Valdez Creek Mine, the sources are not distinct based only on pitting (5 and 25 degrees of freedom, $F = 1.77$, $P = 0.304$).

The cause of this coarser pitting is not clearly understood. It may be due to corrosion similar to above, to pressure solution related to contact with adjacent sand and gravel grains, or to cryogenic driven solution activity while a grain is being transported by glacial ice.

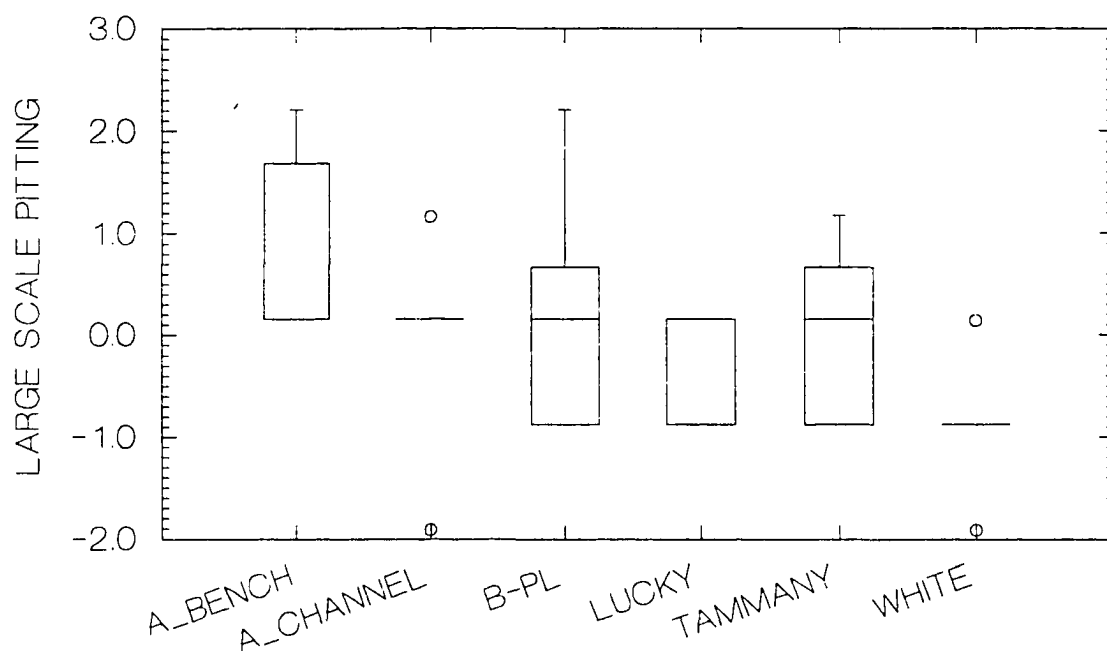


Figure 13-9 Box plot of large scale pitting grouped by channel. Data are standard normal.

14. GOLD FINENESS

14.1. INTRODUCTION

Gold fineness is a relative measure of the gold content of a gold grain or gold ore concentrate by weight. It is commonly expressed as:

$$1) \quad \frac{Au_{wt}}{Total_{wt}} \times 1000$$

or

$$2) \quad \frac{Au_{wt}}{Au_{wt} + Ag_{wt}} \times 1000$$

Thus, 1000 fine is pure gold. The mint assays of the ore from the Valdez Creek Mine are reported by method 1. Silver, and less commonly other metals, may also be reported in units of fineness.

The Au fineness of placer gold is predominantly inherited from the bedrock source. Primary (bedrock) gold deposits have a wide range of gold finenesses, depending on the type of gold deposit. Archean gold deposits have the highest average gold fineness, at 940 fine, while epithermal gold deposits can have an average gold fineness as low as 440 (Morrison *et al.*, 1991). The range of finenesses within a deposit also depends on deposit type: Archean deposits tend to have very restricted ranges (<100 fine), while epithermal deposits can have a very wide range of Au fineness (>500 fine) (Morrison *et al.*, 1991). The average gold fineness and range of fineness of a placer deposit are a function of the fineness of the bedrock source or sources and, therefore, can provide a clue to the nature of that source(s).

While the gold fineness of the interior of a placer gold grain is inherited from the bedrock source, the gold fineness of the surface of the grain may be subject to modification by the secondary environment. The literature cites many examples where high fineness rims have been found on gold grains. The authors of these articles cite the high fineness rims as evidence that gold has precipitated from solution onto the grain (Giusti, 1986; Groen *et al.*, 1987; Clough and Craw,

1989). Interestingly, weathering of a gold grain would also tend to produce a higher fineness surface on the grain, because the other metals found in gold grains have a higher oxidation potential than gold and, therefore, would more readily go into aqueous solution (Desborough, 1970; Gorshkov *et al.*, 1971).

In this chapter, the gold fineness of the interior of the grains is first investigated. Then the gold fineness of the surfaces of the grains and the changes in fineness from the interior to the surface of the grains are examined. Finally, the significance of these results is discussed.

14.2. GRAIN INTERIOR

The gold grains used in the surface pitting study were remounted in one-inch epoxy plugs and ground on a polishing wheel to reveal a cross section of each grain. The cross sections were oriented parallel to the major (length) and minor (thickness) axes. After carefully polishing the plugs, the interior of each grain was analyzed for Au, Ag, Cu, and Hg using a Cameca SX-50 Electron Microprobe at the Department of Geology and Geophysics, University of Alaska Fairbanks. The analyses were done using the wave dispersive spectrometer (WDS) at an accelerating voltage of 20 kV, an incident angle of 90.0 degrees, and an x-ray emergence angle of 40.00 degrees. Au and Ag were analyzed using L alpha x-rays and pure metal standards. Cu was analyzed using K alpha x-rays and a CuFe alloy standard with a Cu weight fraction of 0.3462. Hg was analyzed using L alpha x-rays and a HgTe standard with a Hg weight fraction of 0.6112.

All finenesses in this report are calculated relative to total metal (1 above); however, in this case, there is virtually no difference between the two ways of reporting fineness because the Cu and Hg contents are extremely low. Each grain was analyzed at 20 points equally spaced along a line roughly parallel with the long axis of the grain. The analyses from a single grain form normal populations with low variances (Figure 14-1). Approximately one third of the grains had outliers, ranging from 1 or 2 points in most cases to a maximum of 5 points for one grain. I suspect that the outliers are the results of probe analyses at a scratch or other imperfection in the polish, and I excluded them from further consideration.

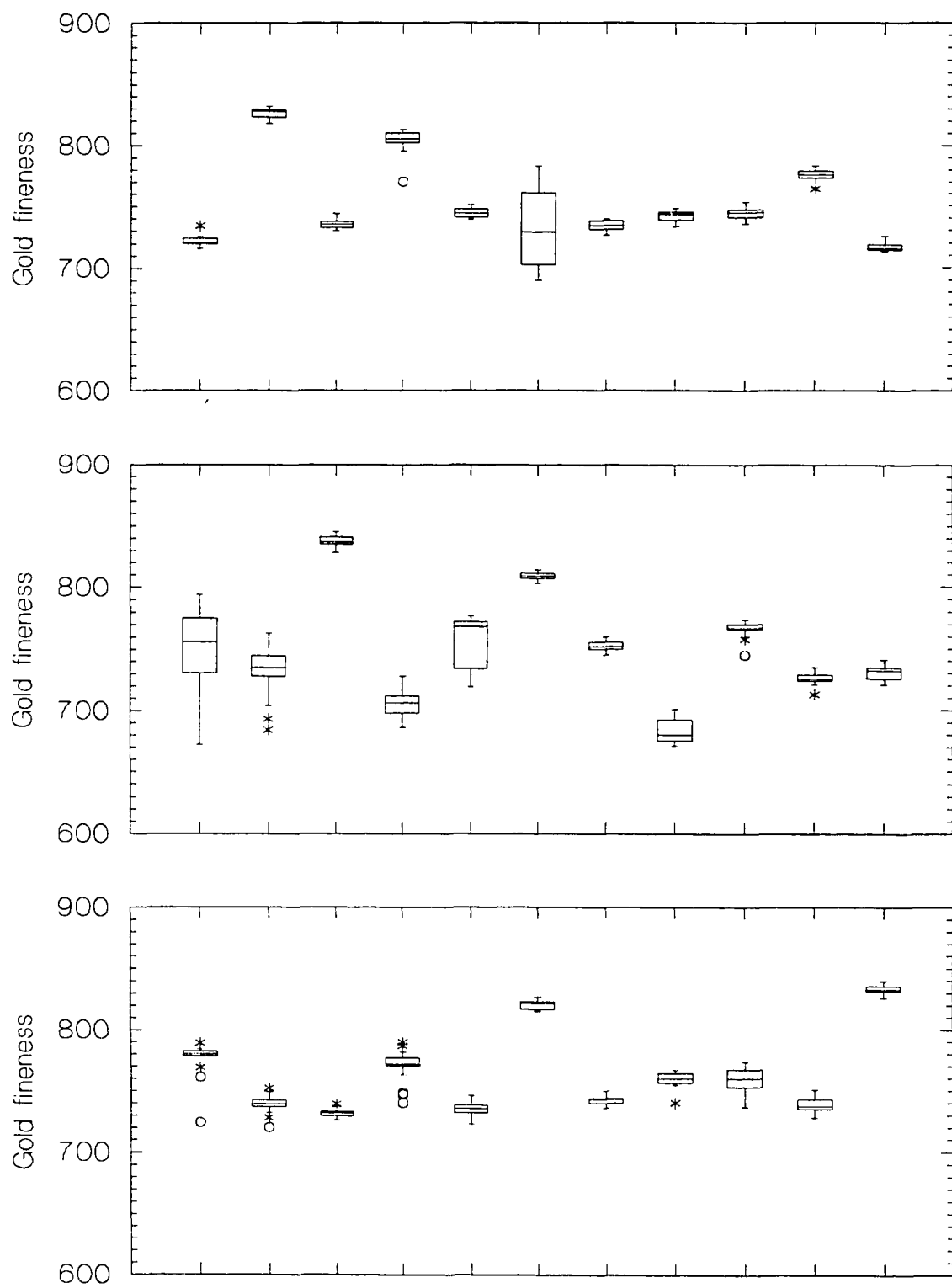


Figure 14-1 Box plots of individual grain interior gold content. Data are untransformed.

To evaluate whether 20 measurements per grain were adequate to determine the composition of a grain, an ANOVA was used to evaluate the within-grain versus between-grain variance for ten randomly selected grains. The 20 analyses for each of these grains were randomly divided into two groups of 10 analyses, and the two groups were considered to be duplicate analyses of each of the grains. An ANOVA (Table 14-1) indicates that there is a significant difference in the mean Au fineness between grains, but that there is not a significant difference in the mean Au fineness between the duplicates; therefore, 20 analyses per grain were more than adequate to characterize an individual grain.

A probability plot of the mean gold finenesses for all 33 grains is shown Figure 14-2. The average gold content of the grain interiors is 756 fine. Deviations from linearity suggest that more than one subpopulation may be present. Modeling, using Probplot (Stanley, 1987), indicates that there are three subpopulations. These results are summarized in Table 14-2. These distinct subpopulations suggest that there was more than one bedrock source for the placer gold, or at the very least, that a single source was distinctly zoned.

The mean interior gold fineness of 756 differs from the fineness of 852 for the Valdez Creek drainage reported by Reger and Bundzten (1990) and known to me through my work on ore reserve definition at the Valdez Creek Mine (confidential mine records, 1988 through 1990). This difference cannot be explained by the contribution of pure gold from a high fineness rim. Using a high fineness rim that averages 1 μm thick, an interior fineness of 756 and a rim fineness of 955 (see the next section for the basis of rim assumptions; because no data exist concerning average rim thickness, the value represents the maximum likely to be found), and assuming a round disk with a width to thickness ratio of 1 to 0.254 (see Chapter 12), calculations indicate that the average grain size at the mine would have to be between 17 and 18 μm to result in an average of 852 fine. Although the average grain size of the gold collected at the mine has never been determined, this is clearly too small. The most likely explanation for this difference in fineness is that the fineness of the gold at Valdez Creek varies with grain size. Only +20 mesh gold grains were used in this study, with the grains averaging 4.09 by 2.78 by 0.73 mm in size (Table 10-1). Other size fractions apparently have higher fineness gold grains. A future area of research would be to investigate this difference in fineness, for instance, determine the distribution of gold grain fineness

with grain size and whether the findings of this thesis remain the same for a different grain size fraction that has a different mean gold grain fineness.

The mean gold fineness of the interior of the grains, broken down by channel, is plotted in Figure 14-3. An ANOVA of grain interior gold fineness by channel indicates there is no significant difference between the mean fineness of the grain interiors from different channels (5 and 24 degrees of freedom, F-ratio = 0.763, resulting in a probability of 0.586). This might suggest that the source(s) is not zoned. If the source(s) was zoned, the oldest channel should have gold from the upper or northern part of the deposit (the strong asymmetry of the Valdez Creek drainage indicates that the tributaries experienced southerly-directed headward erosion over time), and the youngest channel should have gold with a different fineness from the lower or southern part of the deposit. However, there are three subpopulations, which indicates there is indeed zoning within one source or that there are three sources with differing free gold fineness. The thresholds for the 3 subpopulations are also plotted in Figure 14-3 and described in Table 14-2. Subpopulation 1 is an anomalously low fineness grain found in the A Bench, and Subpopulation 3 is found in A Bench, A Channel, Lucky Gulch, and as one outlier in the B-PI Channel. Also, there is a marked decrease in variability in gold fineness between the channels in the sequence plotted, if one temporarily excludes Lucky Gulch from consideration (which is reasonable if the source(s) is located predominantly in the White Creek drainage). The channels are plotted from oldest to youngest with the exception of the B-PI Channel. This may be an indication that the relative age of the B-PI Channel should be reconsidered.

There appears to be zoning in the bedrock source(s), based on the existence of three subpopulations and the apparent decrease in variability with time. This will be further evaluated in Section 16.4, after the relative age of the channels is better defined.

The bedrock source for the gold in the Valdez Creek valley may be metamorphically related or it may be related to the numerous small igneous bodies. A goal of this study has been to determine, if possible, the nature of the source deposit based on the composition of the gold derived from the deposit. Unfortunately, very little work has been done in compiling data on the fineness of the gold in deposits relative to deposit type. Considerable data are available concerning ore grades, but there is relatively little available concerning the fineness of the gold itself. One study by Morrison *et. al* (1991) compiled gold fineness data for many deposits and

Table 14-1 Nested analysis of variance of duplicate analyses of grain interior gold content. Duplicate test consisting of 2 sets of 10 analyses each for 10 grains.

Null hypothesis: 1) There is no difference between the mean interior gold fineness of each grain.
2) There is no difference between the mean interior gold fineness of each duplicate sample from a grain.

Alternative: 1) The mean interior gold fineness of at least one grain is significantly different than the mean interior gold fineness of the other grains. 2) For at least one grain, the mean interior gold fineness of one sample of mean interior gold fineness is significantly different from the duplicate sample of mean interior gold fineness from the same grain.

Criterion: Reject null and accept alternative at a probability equal to or less than 0.05.

SOURCE	SUM-OF-SQUARES	D.F.	MEAN-SQUARE	F-RATIO	PROBABILITY
GRAIN	283477	9	31794	204.873	0.000
DUP{GRAIN}	451	10	45	0.294	0.982
ERROR	26751	174	153		

Dependent variable is grain interior gold fineness.

DUP{GRAIN} means duplicate within grain.

Conclusion: There is no significant difference between duplicate samples of interior gold fineness of the same grain, but there is a significant difference in the interior gold fineness between grains.

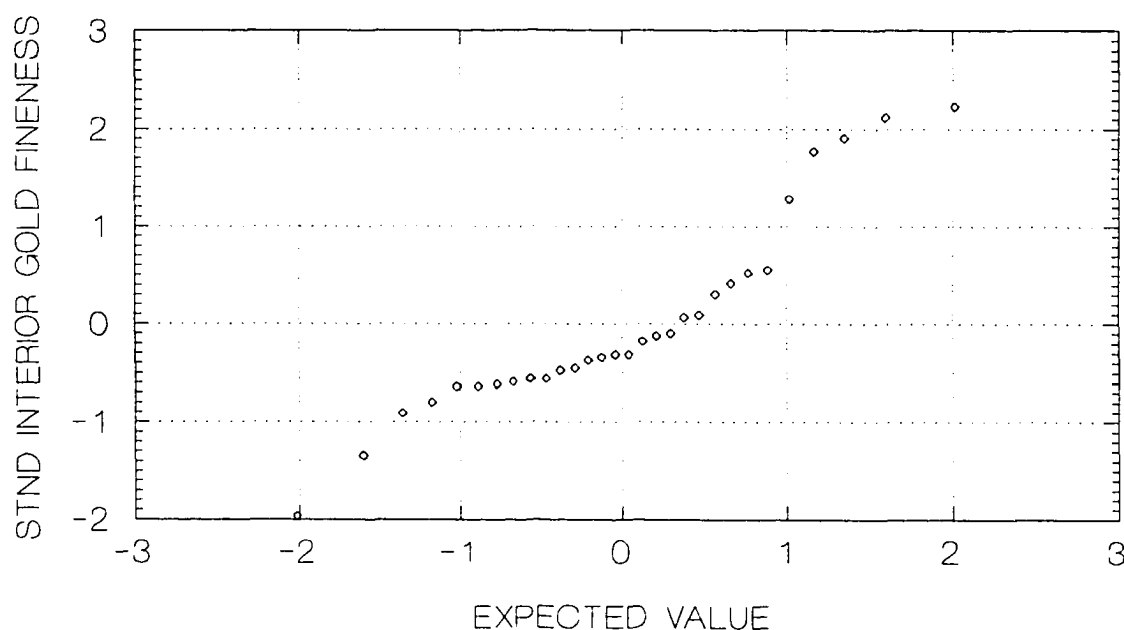


Figure 14-2 Probability plot of the mean gold content of the interior of the gold grains. Data are standard normal.

Table 14-2 Basic statistics for the interior gold content of the entire sample population of gold grains and for three subpopulations.

POPULATION	MEAN	STANDARD DEVIATION	NUMBER	PERCENTAGE	THRESHOLDS	
					LOWER	UPPER
ALL	755	36.9	30	100	--	--
1	688	11.3	1	4	<	710.5
2	745	16.9	24	79	711.5	777.5
3	824	12.3	5	17	799.5	>

All data units are "fine."

Thresholds represent the upper and lower limits of the data that can be classified into the given population.

The range between the upper threshold of one population and the lower threshold of the next higher population could belong to either population.

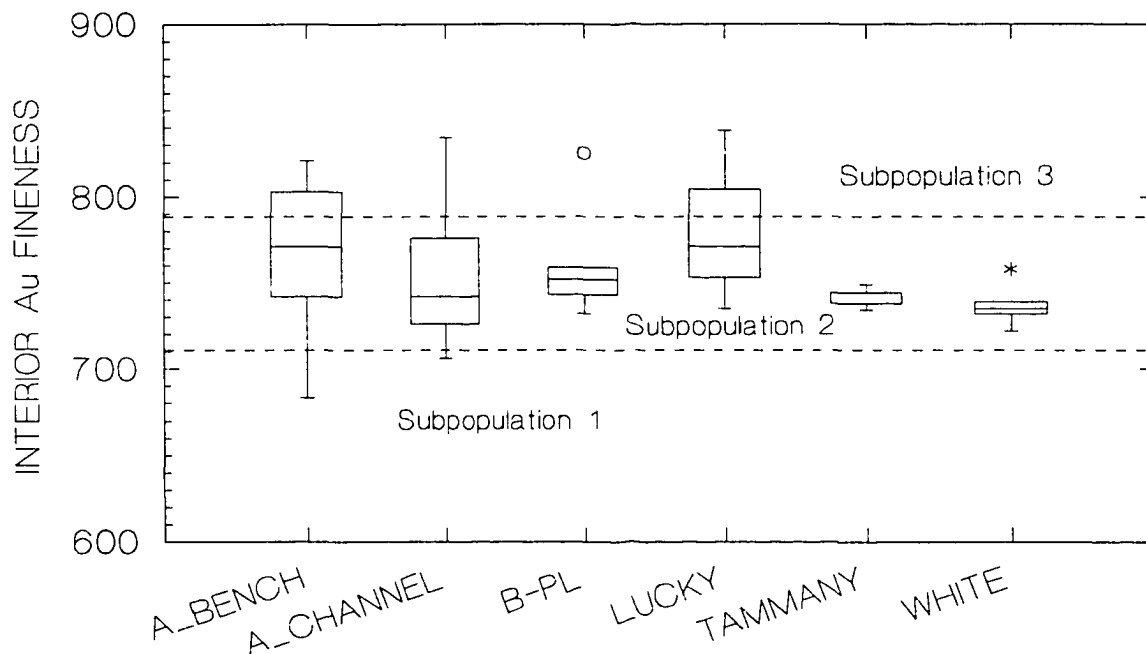


Figure 14-3 Box plots of grain interior gold content by channel. The thresholds for the three subpopulations are also plotted. Asterisks show outliers, circles show extreme outliers. Data are untransformed.

classified the data into six deposit types. However, there appear to be problems in classifying deposits.

Probably the most useful comparison is to deposits in similar environments regardless of deposit models. The geologic environment of Valdez Creek is very similar to that of the Alaska-Juneau (A-J) Mine. The Gravina Formation and MacLaren Metamorphic Belt rocks have very similar depositional environments (S.M. Karl, U.S.G.S., verbal communication, 1990), and both deposits are located near a very high-gradient transition to high-grade metamorphic rocks. The gold at the A-J Mine is reported to be 850 fine (Morrison *et. al*, 1991), which is somewhat finer than the average fineness of 755 for Valdez Creek gold found in this study. Another possible comparison is to the Mother Lode deposit in California, which has an average gold fineness of 780 to 830 (Morrison *et. al*, 1991), intermediate between that of the A-J and Valdez Creek. Although the gold fineness at Valdez Creek is in the same range as these deposits, I am unable to draw any conclusions concerning the type of deposit from which the gold at Valdez Creek was derived, due to the lack of documentation in the literature.

14.3. GRAIN SURFACE

The metal content of the surface of the gold grains was analyzed using the same whole grain mounts as were used for the imaging of the surface of the grains. The Kevex Model 8005 Energy Dispersive Spectrometer (EDS) on the AMR Model 1000A Scanning Electron Microscope, U.S.B.M. Albany Research Center, Albany, Oregon, was used. The ZAF corrections were via Magic V. The beam was allowed to move over a small area in order to minimize the effects of local irregularities and to obtain results over a discrete portion of the grain, rather than from a single point. The SEM, rather than the microprobe, was used for the surface analyses because the analyses are from an irregular, curved surface rather than a flat polished surface. Though the SEM handles this situation somewhat better, the results should be considered semi-quantitative. At an accelerating voltage of 20 kV, in a specimen composed predominantly of gold, the characteristic x-rays are generated at a depth of up to 0.4 μm (Potts, 1987, modified by Ken Severin, UAF, verbal communication, 1995); therefore, the thickness of the surface layer that was measured and is herein referred to as "surface fineness" is 0.4 μm . The actual thickness may be somewhat less-- if it is less, the value reported here is a weighted average of the gold content of the surface layer

and the underlying interior to a depth of 0.4 μm . The maximum thickness is approximately 2 μm . If thicker than 2 μm , the surface layer would have been seen in the cross sectional scans of interior gold content (“interior fineness”), where it was not detected (Section 14.2).

The population of surface fineness analyses is shown in Figure 14-4. The large positive skew can be corrected by an exponential (10 power) normalization (Figure 14-5). A single spot on the surface of each grain was analyzed. Duplicate analyses on a limited number of grains indicate there is not a significant difference between the Au fineness of duplicate analyses, but there is a significant difference between grains at $\alpha = 0.05$.

Table 14-3 lists the basic statistics for surface fineness, interior fineness, and the change in fineness from surface to interior. The surface of the grains, with a mean gold content of 955 fine, is 26.7% finer than the interior of the grains (mean of 755 fine). Figure 14-6 shows that there is no correlation between the interior and surface fineness ($r = 0.306$), nor between surface fineness and the change in fineness ($r = 0.363$), but interestingly, there is a significant inverse correlation between interior fineness and the change in fineness ($r = -0.764$). This high negative correlation indicates that the change in fineness is a function of the impurities (predominantly silver) in the gold grain. The higher the silver content of the grain, the more difference there is between the fineness of the interior of the grain and the fineness of the surface.

There is no significant difference between the mean fineness of the interior of the grains for the different channels (Figure 14-3). As would be expected from the high correlation between IFINE and DELTA, there is also no significant difference, at the 95% confidence level, in the mean change in fineness between the channels, based on an ANOVA (Figure 14-7 and Table 14-4). There is, however, a significant difference (95% confidence) between channels in the mean fineness of the surface of the grains (Figure 14-8 and Table 14-4). The fineness of the surface of the grains has changed by varying amounts, resulting in a uniform and distinct surface fineness for gold from each channel.

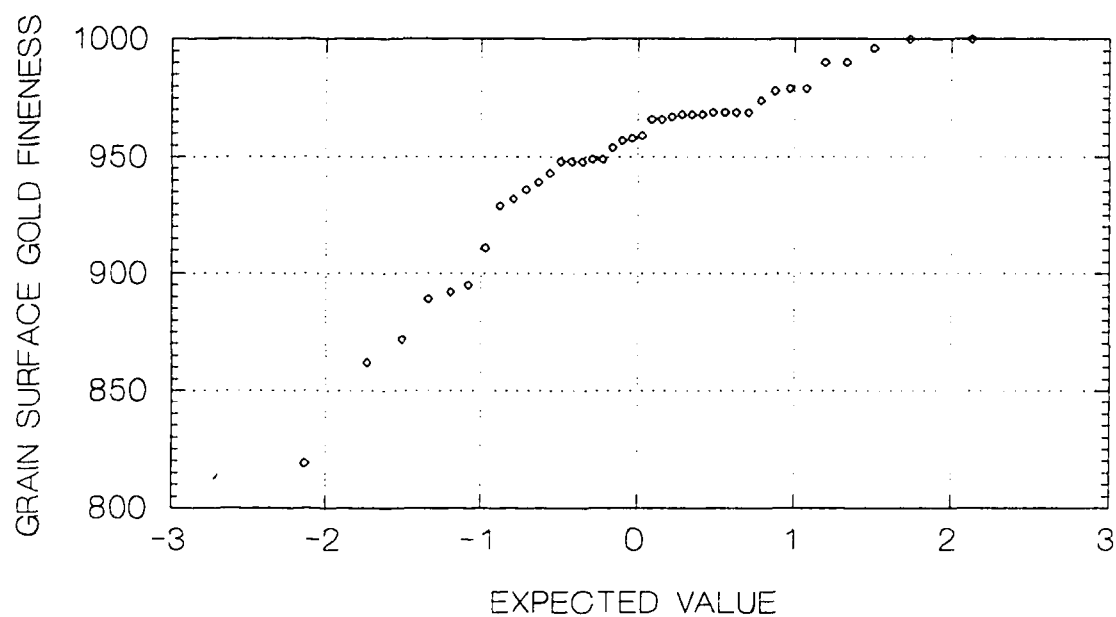


Figure 14-4 Probability plot of grain surface gold content (untransformed data).

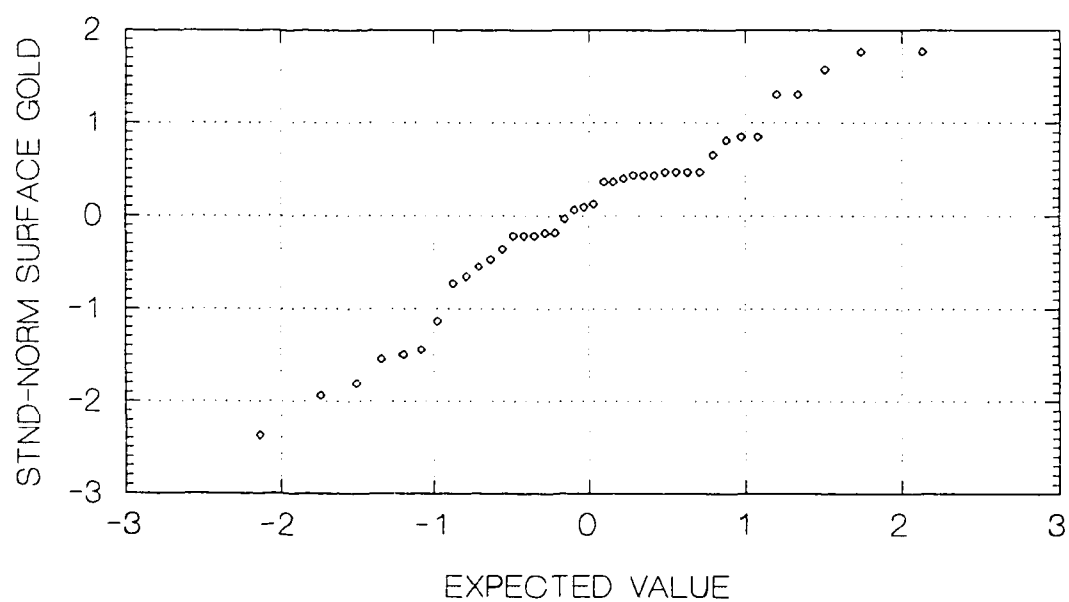


Figure 14-5 Probability plot of grain surface gold content (standardized and normalized).

Table 14-3 Basic statistics for grain fineness (interior, surface, and change).

	INTERIOR (fine)	SURFACE (fine)	CHANGE (%)
Distribution	normal	exponential	normal
No. of cases	30	40	30
Minimum	683	819	13.2
Maximum	838	1000	41.7
Mean	755	955	26.7
- 1 Std Dev	718	917	20.3
+ 1 Std Dev	792	983	33.1

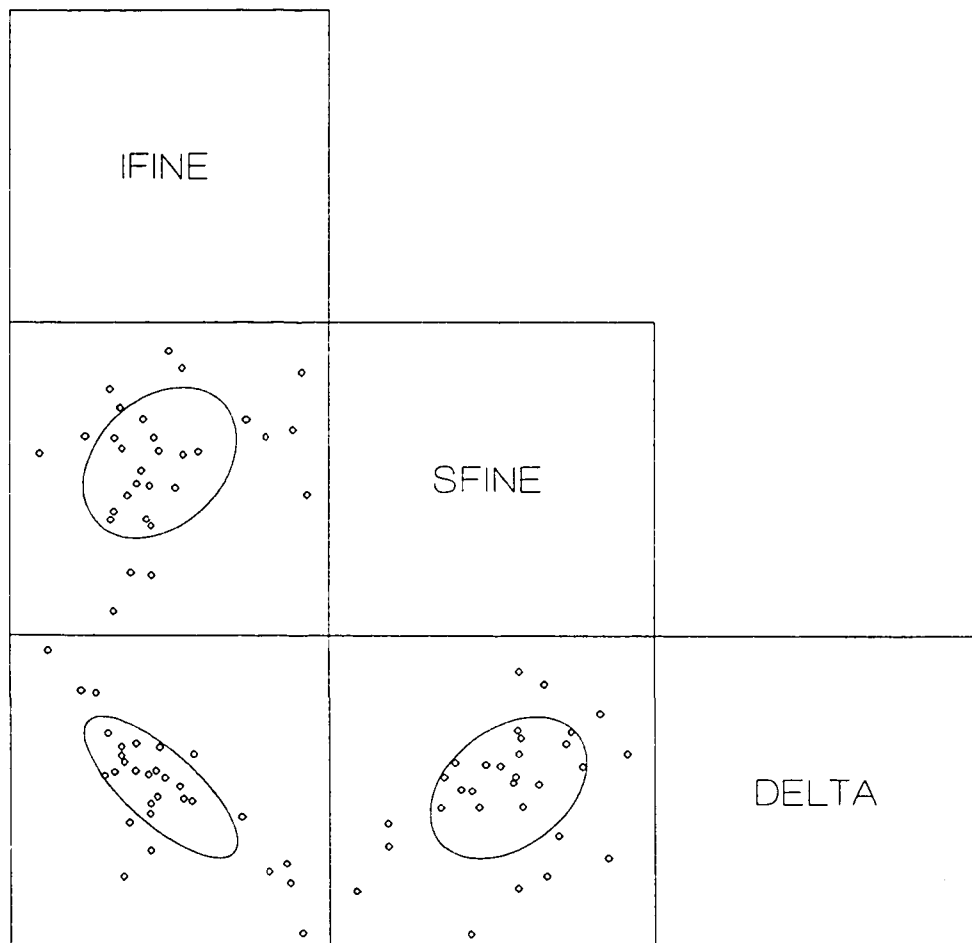


Figure 14-6 Scatter plot matrix of grain surface (sfine) and interior (ifine) gold content, and change (delta) in gold content between surface and interior (standard-normal data).

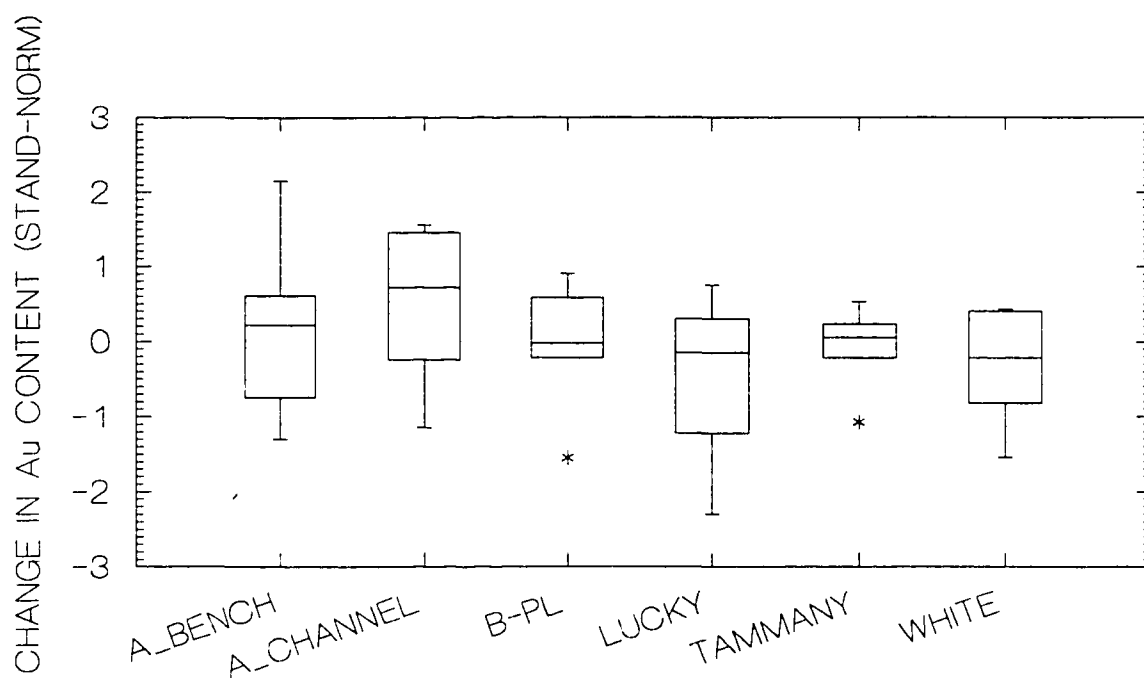


Figure 14-7 Box plots of change in gold content between surface and interior of grain by channel (standard-normal data).

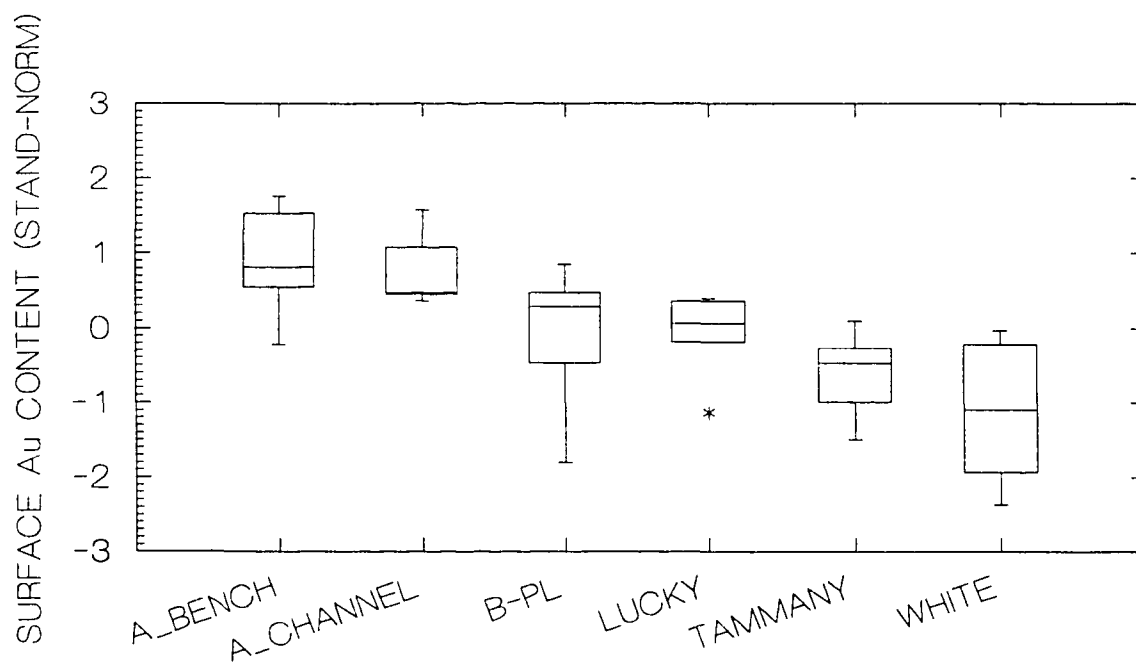


Figure 14-8 Box plots of grain surface gold content by channel (standard-normal data).

Table 14-4 Summary of ANOVA results for grain gold contents by channel.

Null hypothesis: There is no difference in the mean gold content of the grains from a channel from the mean gold content of the grains from any other channel.

Alternative: The mean gold content of the grains from at least one channel is not equal to the mean gold content of the grains from the other channels.

Criterion: Reject the null and accept the alternative hypothesis if the probability is less than or equal to 0.05.

	Degrees of Freedom	F Ratio	Probability
Interior Gold Fineness	5, 24	0.763	0.586
Surface Gold Fineness	5, 34	7.775	0.000
% Change	5, 24	0.639	0.672

Conclusion:

- 1) There is no significant difference in the mean interior gold fineness of the grains from one channel, compared to the other channels.
- 2) There is a significant difference in the mean surface gold fineness of the grains from at least one channel.
- 3) There is no significant difference in the mean change in gold fineness from the interior to the surface of the grains from one channel, compared to the other channels.

14.4. DISCUSSION

In the chapter on surface morphology, the pervasive pitting of the grains was presented as evidence that the placer gold had been subject to corrosion. In this chapter, evidence supporting corrosion has been presented. The difference in gold fineness and the resulting uniform fineness of gold at the surface of the grains from each channel are most likely the result of corrosion.

Numerous recent studies have focused on the weathering of silicate minerals. These studies have shown that etch pits, often coalescing, are the result of chemical weathering of silicate minerals (Berner *et al.*, 1980; Berner and Schott, 1982). The chemical nature of the weathering of silicate minerals has been studied for decades, with a number of processes being proposed (Petrovic *et al.*, 1976), including hydration of a thin layer (Lasaga and Blum, 1986; Knauss and Wolery, 1988) and cation depletion of a thin layer (Berner and Schott, 1982; Mogk and Locke, 1988).

Interestingly, studies of the “weathering” of detrital gold grains have led to quite different conclusions. A number of researchers (Giusti, 1986; Groen *et al.*, 1987; Clough and Craw, 1989) have found high gold fineness rims on gold grains. They cite these rims as evidence of precipitation of gold from aqueous solution. These researchers have concluded that gold grains have experienced supergene growth in the secondary environment, rather than solution and removal of material at the mineral surface as has been found with silicates. It would not be entirely surprising that detrital gold might weather differently from silicate minerals. Detrital gold, actually a gold-silver alloy (electrum), is composed of noble metals, while the silicates are molecular combinations of cations (Ca^{+2} , Na^+ , K^+ , Mg^{+2} , etc.) and silica oxide and lesser aluminum oxide anions. Weathering of gold is an electro-chemical (oxidation-reduction) process, while silicates weather mostly by various cation-exchange processes.

The gold-rich rims found on grains in other studies were not found on the gold grains used in this study. Figure 14-9 and Figure 14-10 show the results of two microprobe traverses across gold grain cross sections. Analyses were taken at 2 μm intervals. If a rim exists, it is less than 2 μm thick. Rims reported in other studies varied from 1 to 30 μm thick (Desborough, 1970; Giusti, 1986; Groen *et al.*, 1987). The rind of cation depletion found on silicates is reported to be from 5 to 20 Å (0.5 to 2.0×10^{-3} μm) (Berner and Schott, 1982) up to 1200 Å (0.12 μm) thick (Mogk and Locke, 1988), or two to four orders of magnitude smaller than reported for gold grains. Early in this study Au-rich rims were provisionally recognized; however, a marked increase in the variability of the measured fineness and a lack of change in reflectance of the “rim”, relative to the interior of the grain, led me to suspect the data. I eventually concluded that the apparent gold-rich rim was a data artifact caused by edge rounding during polishing. This rounding resulted in a shift toward the heavier element (Ag to Au) in the ZAF correction routine.

The susceptibility of gold to corrosion (at surface temperatures and pressures) is a function of the oxidation potential of the possible reactions. Table 14-5 lists the oxidation potential for some common reactions involving gold and silver. Silver half-reactions have lower oxidation potentials than gold reactions; therefore, silver will oxidize and go into solution first, thus explaining the depletion of silver at the surface of the placer gold grains analyzed in this study.

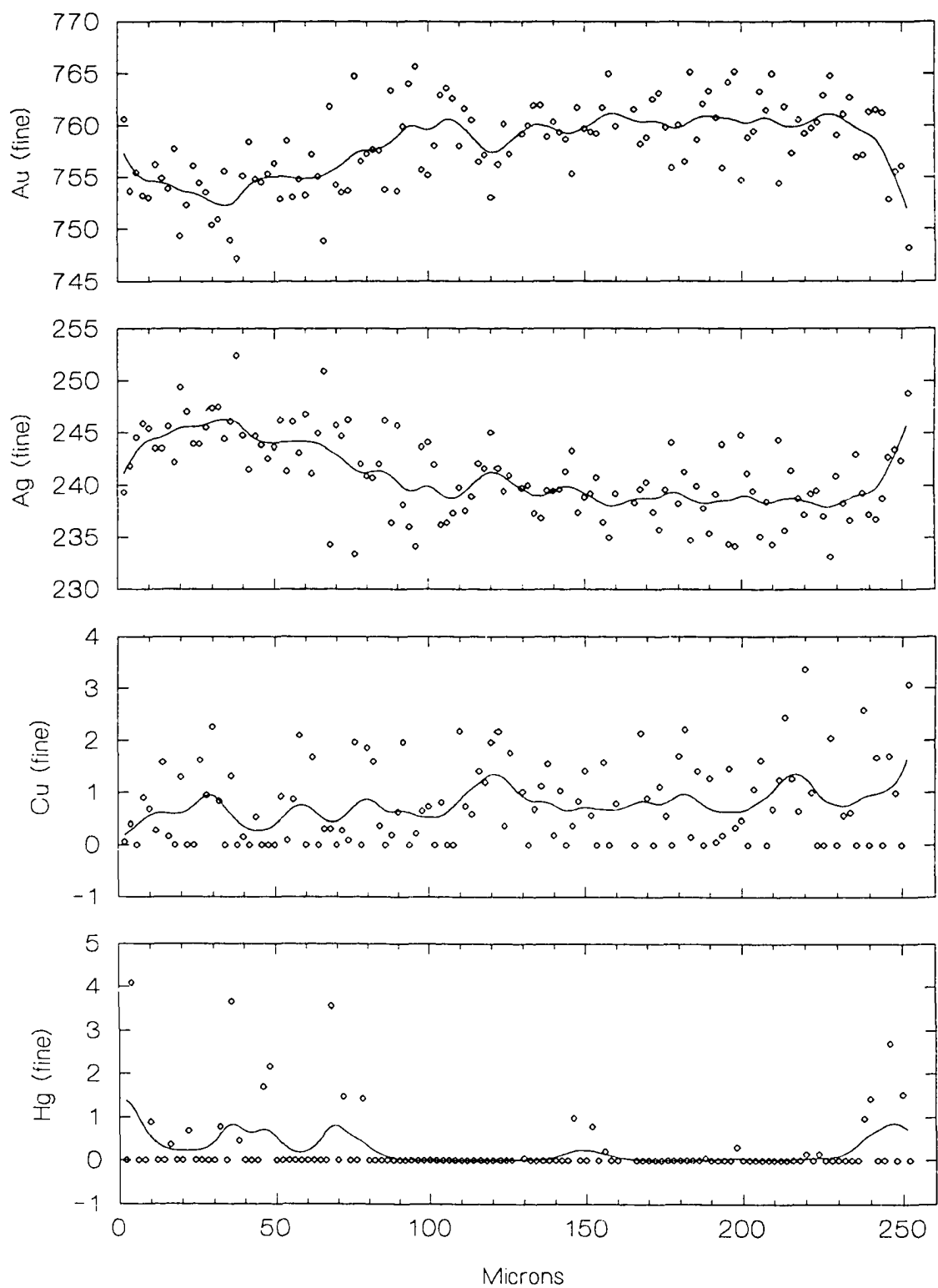


Figure 14-9 Au, Ag, Cu, and Hg contents of the cross section Grain 81 from the Tammany Channel (untransformed data, lines fitted using distance weighted least squares smoothing [SYSTAT, 1992]).

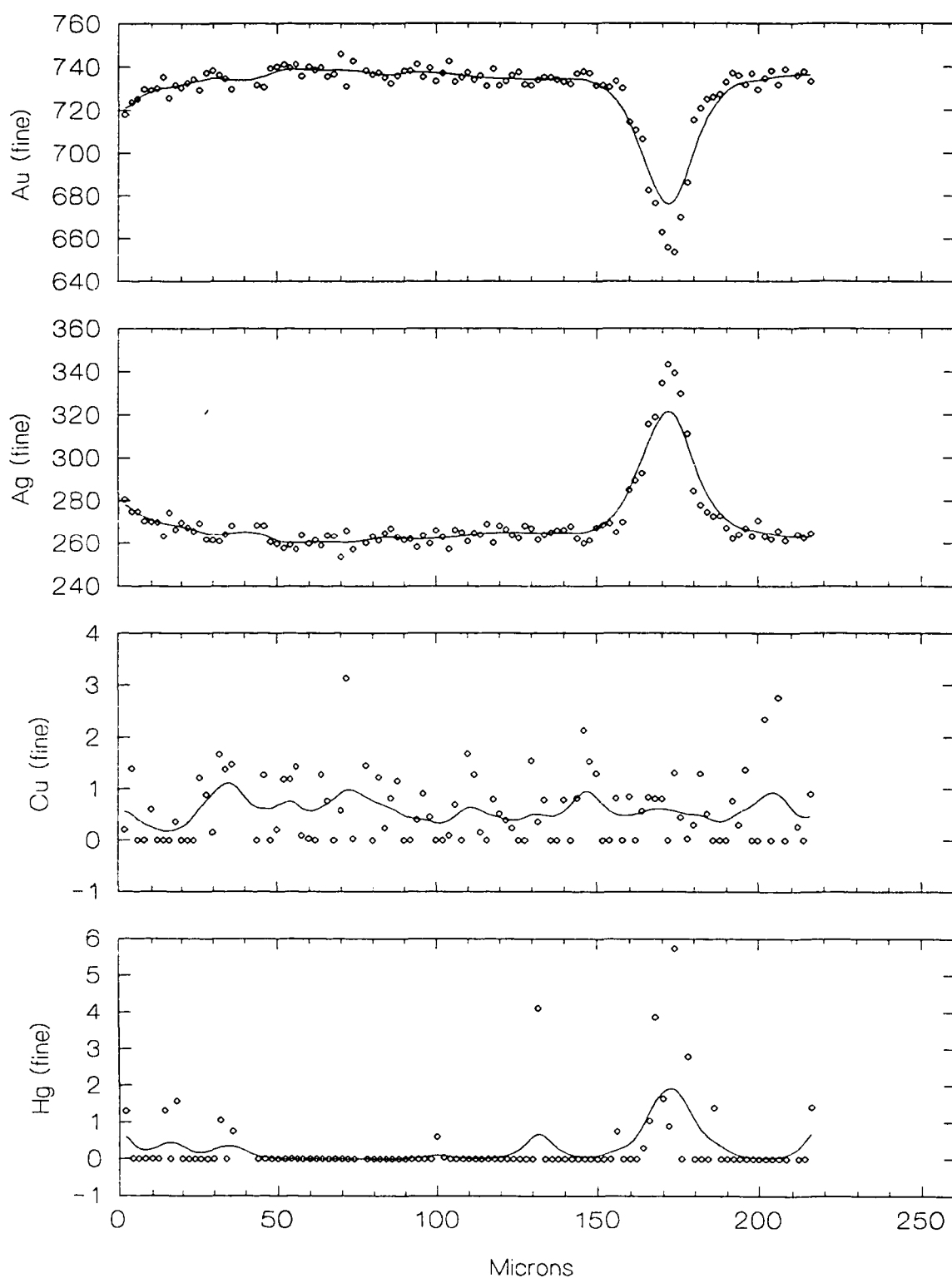


Figure 14-10 Au, Ag, Cu, and Hg content of the cross section of Grain 7 from White Creek (untransformed data, lines fitted using distance weighted least squares smoothing [SYSTAT, 1992]).

Table 14-5 Oxidation potential of selected half-reactions at 25° C and 1 atmosphere pressure.

	E°
$\text{Ag} + \text{Cl}^- = \text{AgCl} + \text{e}^-$	+0.22
$\text{Ag} = \text{Ag}^+ + \text{e}^-$	+0.80
$\text{Au} + 4\text{Cl}^- = \text{AuCl}_4^- + 3\text{e}^-$	+1.00
$2\text{H}_2\text{O} = \text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^-$	+1.23
$\text{Au} = \text{Au}^{3+} + 3\text{e}^-$	+1.46
$\text{Au} = \text{Au}^+ + \text{e}^-$	+1.68

The pitting probably occurs at either of two sites: 1) silver-rich locations in the grains or 2) crystal imperfections. The latter are the site of etch pit formation in silicate grains (Helgeson *et al.*, 1984; Lasaga and Blum, 1986). No silver inhomogeneities were found during microprobe analysis; therefore, any such inhomogeneities, if they exist, must be smaller than the probe beam excitation bulb (approximately 0.5 μm). It is probable that pitting is occurring at both types of sites.

The existence of the corrosion pits clearly demonstrates that the gold grains have been corroding, or in other words, oxidizing. Since the geochemical environment is oxidizing rather than reducing, the higher gold content of the surface of the grains must be due to loss of silver and other impurities (oxidation), not due to precipitation of gold (reduction).

The overall oxidation rate of gold is probably very slow. The exponential distribution of the surface gold fineness would seem to indicate that initially corrosion is more rapid, slowing with time. It is also evident in Figure 14-8 that there is little difference in the surface fineness of the grains in the older channels (B-Pl, A Bench, and A Channel). This might suggest that there is not a large age difference between these channels (as may be the case for the A Bench and the A Channel). I think the most likely explanation is that, after a certain length of time, a dynamic equilibrium is reached and further oxidation removes gold and silver in approximate stoichiometric balance.

Analyses of the fineness of the surface and the interior of the gold grains have shown that the grains corrode with a preferential leaching of silver. The amount of silver leached is directly related to the amount of silver in the grain, but tends toward a uniform gold fineness for each channel. The average fineness for each channel appears to correlate with the probable relative ages of the channels, suggesting that silver is leached preferentially at first, but that a dynamic equilibrium is established after which silver is leached only slightly in preference to gold. The surface fineness of gold grains in a placer deposit, therefore, can be used as a relative dating tool.

15. MULTIVARIATE STATISTICAL ANALYSIS

15.1. INTRODUCTION

A number of variables describing surface morphology, size, shape, and gold content of the +20 mesh gold grains have been examined in order to understand the character of the placer gold deposited in the Valdez Creek drainage. In this chapter, the results of multivariate statistical tests are presented. The objective of these tests is to identify a particular combination of the individual variables that describes any underlying factors controlling the character of the placer gold in the Valdez Creek Drainage. The discriminant analysis is most useful because the grains were collected from different channels; the channels are an important grouping variable. A cluster analysis has also been performed to see if there is any underlying structure that is independent of the channel grouping.

15.2. CORRELATIONS

Many variables were examined as potential descriptors of the gold grains from Valdez Creek. The following variables have been shown to be statistically valid:

Corey Shape Factor (CSF)

Sphericity (SPH)

Pitting (PITTING)

Regularity (REG)

Surface Au Fineness (SFINE)

Interior Au Fineness (IFINE)

Change in Fineness (DELTA)

Four other variables, which may be used only if the analysis is restricted to the paleochannels in the Valdez Creek Mine area, were examined. These variables are the following:

Weight (WT)

Length (LG)

Width (WTH)

Thickness (TH)

The correlations between these variables are shown in Figure 15-1. The following variables are significantly correlated at the 95% confidence level:

CSF, SPH

CSF, TH

IFINE, DELTA

WT, LENGTH, WTH, TH

Table 15-1 Pearson correlation matrix for the seven statistically valid variables.

	CSF	PITTING	IFINE	SFINE	REG	SPHERE	DELTA
CSF	1.000						
PITTING	-0.423	1.000					
IFINE	-0.198	-0.037	1.000				
SFINE	-0.297	0.317	0.306	1.000			
REG	-0.264	0.483	-0.008	0.373	1.000		
SPHERE	0.811	-0.313	0.052	-0.242	-0.078	1.000	
DELTA	0.008	0.331	-0.680	0.475	0.399	-0.070	1.000

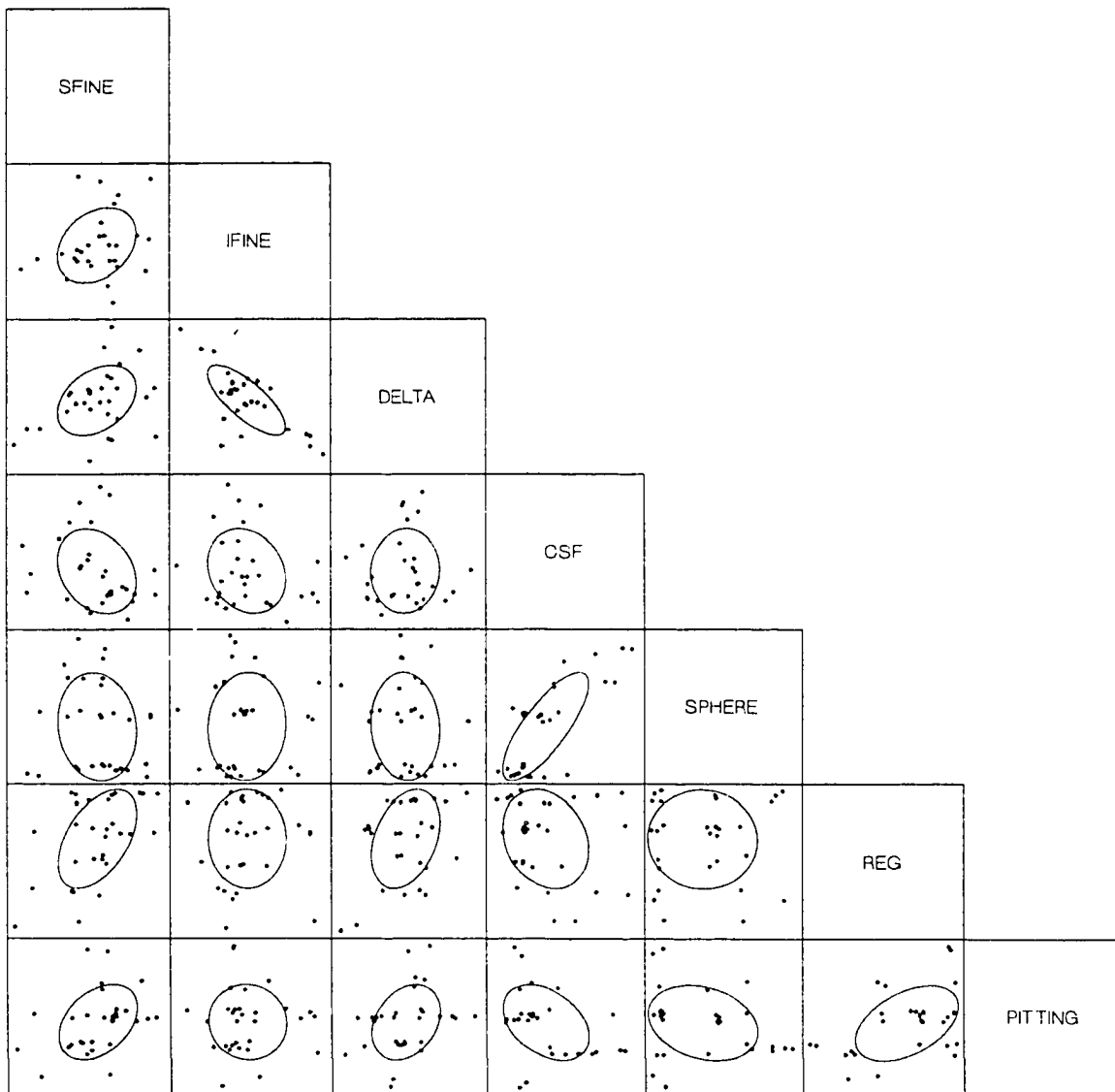


Figure 15-1 Scatter plot matrix of seven variables that are valid throughout the study area.

15.3. DISCRIMINANT ANALYSES

The results of three discriminant analyses are considered. The discriminant analyses were performed using the Multivariate General Linear Hypothesis module of the micro-computer program SYSTAT (1992). The General Linear Model routine was used, with SOURCE (the channel from which the grain was collected) as the independent and categorical variable, and different sets of variables describing the grains (discussed below) as the dependent variables. The effect of SOURCE was then tested, rotating on two canonical variables, and then the canonical scores were saved as the FACTORS. Finally, the FACTORS were plotted in order to visualize the results and to aid in interpretation.

The first discriminant analysis will be for all six of the channels investigated in the study and uses the seven statistically valid variables (Section 15.2) as the dependent variables. The independent variables are SFINE, IFINE, DELTA, CSF, SPH, REG, and PITTING. The results, after a two factor varimax rotation, are presented in Table 15-2 and Figure 15-2. The first factor is significant at greater than 99% confidence level. This factor has approximately equal loadings on the two variables describing the overall shape of the grains--CSF and sphericity (0.593 and 0.510, respectively). The second factor is not significant with an 89% confidence level. This factor has a strong loading on Surface Fineness (0.959).

Table 15-2 Rotated canonical loadings on first 2 factors from first discriminant analysis (seven variables and all six channels).

	FACTOR 1	FACTOR 2
CSF	0.593	-0.042
REG	-0.467	0.310
PITTING	-0.184	0.277
SFINE	-0.097	0.959
IFINE	0.158	0.322
DELTA	-0.165	0.219
SPHERE	0.510	0.033

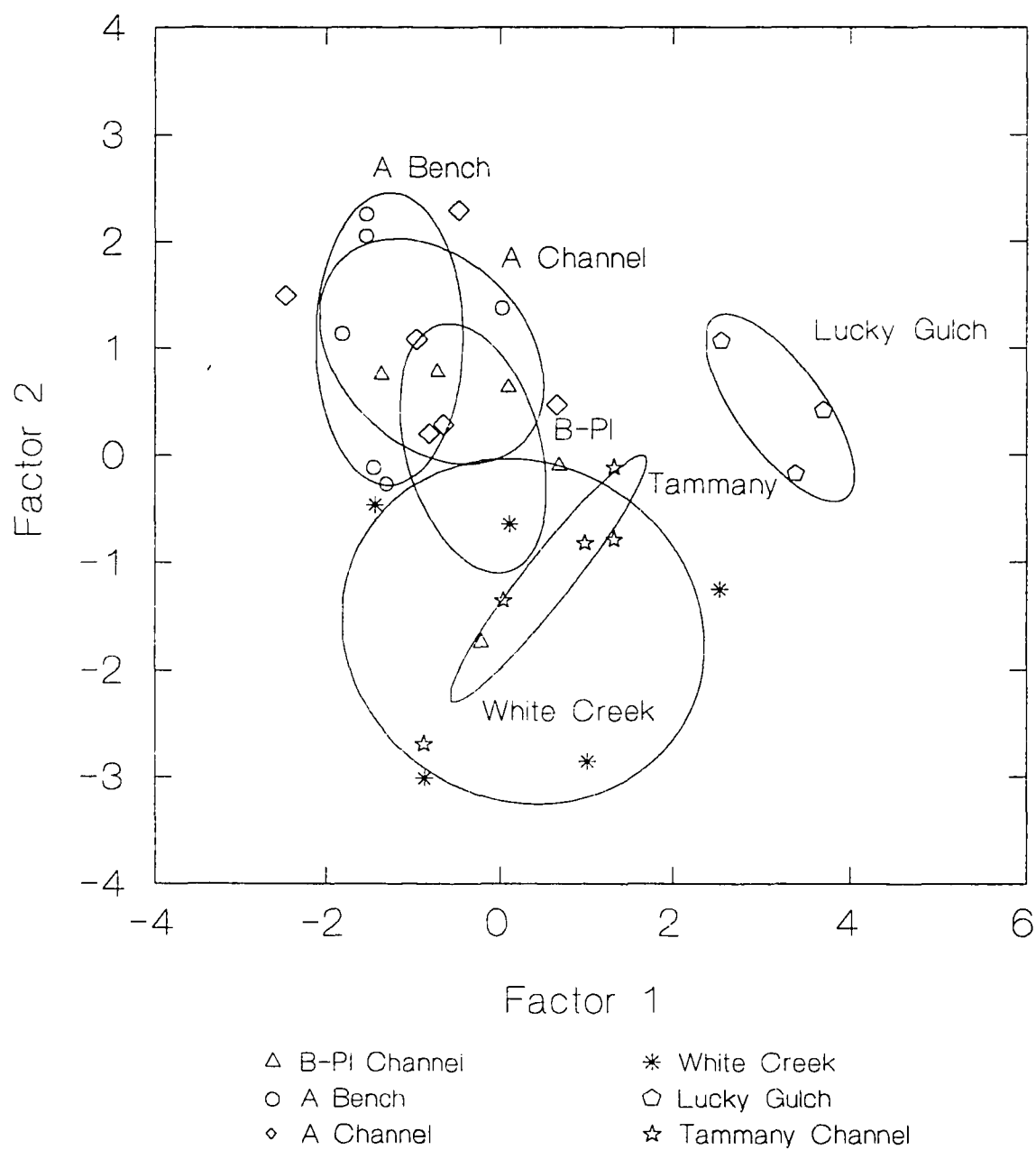


Figure 15-2 Plot of first two factors from first discriminant analysis. Analysis on all valid variables (SFINE, IFINE, DELTA, REG, SPH, CSF, PITTING) that describe grains from all six channels. Varimax rotation on 2 factors.

The second discriminant analysis also includes all of the channels, but the variables SPH, IFINE, and DELTA were dropped. CSF and SPH measure the same property; CSF is used instead of SPH because SPH is categorical data and, therefore, is weaker data than CSF. The variables IFINE and DELTA were dropped because 25% of the data for these two variable is missing because of plucking during polishing. A discriminant analysis is sensitive to missing data in that a case (i.e., a grain) is excluded if any of the variables describing it are missing. By dropping these two variables, all grains were used in this analysis. Thus, the dependent variables are SFINE, CSF, REG, and PITTING, and the analysis is run on 40 grains from all six channels. The first two factors are significant at greater than the 99% confidence level; the third factor is significant at greater than the 95% confidence level. A varimax rotation of the first two factors was found to produce the best results. A plot of these two factors can be found in Figure 15-3 and the canonical loadings are shown in Table 15-3. Factor 1 has a high inverse loading on CSF (-0.786) and a subordinate direct correlation with regularity (0.571). Factor 2 has a very high loading on surface gold fineness (0.944). These results are very similar to the results of the first test. One factor is highly correlated with the overall shape of the grains (CSF), and the other factor is highly correlated with the surface fineness of the gold grains. In the second analysis, the surface fineness factor (Factor 2) is significant, giving some qualitative confidence in the Factor 2 in the first analysis. A comparison of Figure 15-2 and Figure 15-3 indicates the channels have the same relationship to each other, with a sequence of A Bench, A Channel, B-Pl Channel, Tammany Channel, and White Creek; Lucky Gulch is located off trend.

Table 15-3 Rotated canonical loadings on first 2 factors from second discriminant analysis (four variables and all six channels).

	FACTOR 1	FACTOR 2
CSF	-0.786	0.029
REG	0.571	0.235
PITTING	0.268	0.317
SFINE	0.018	0.944

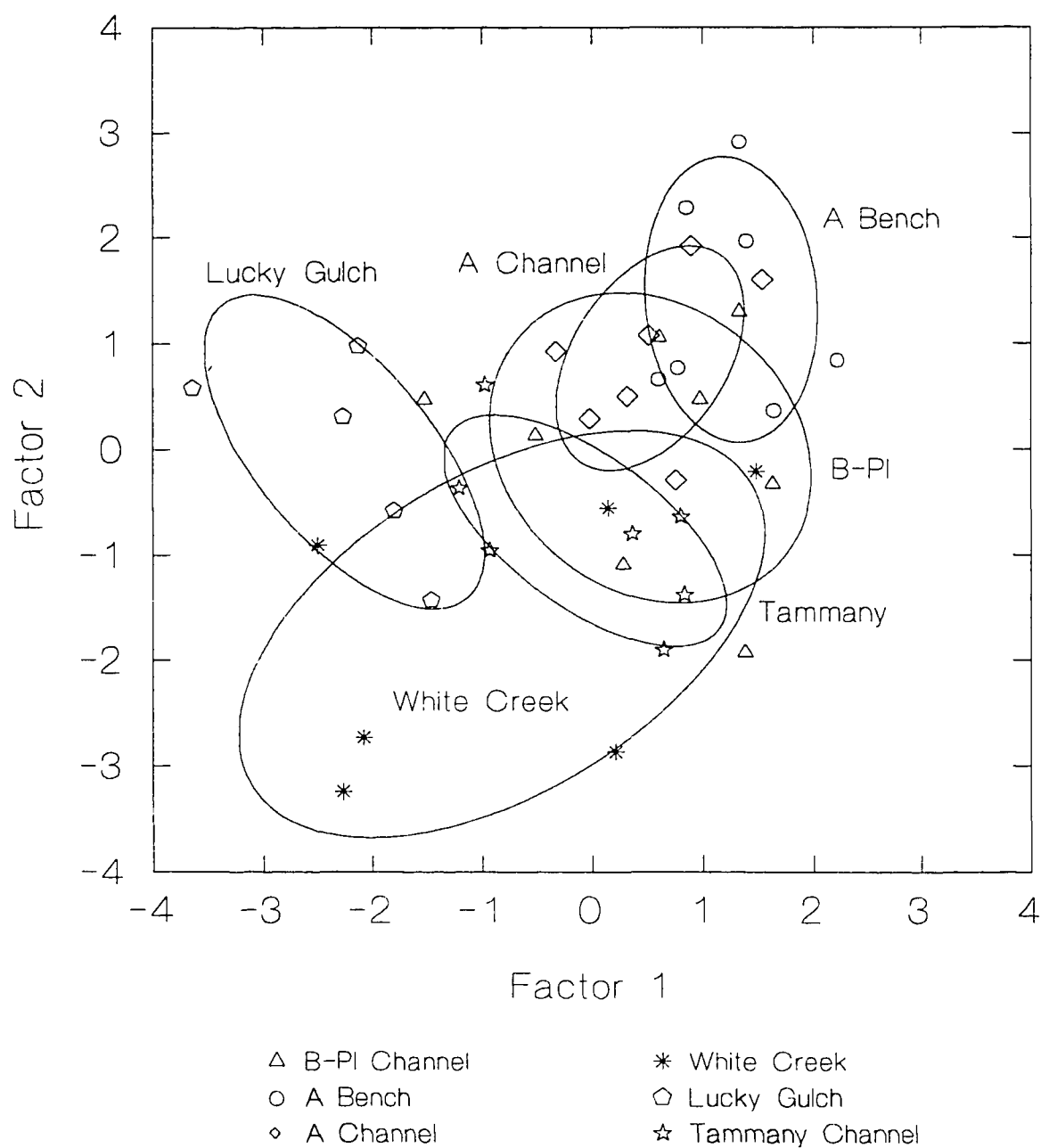


Figure 15-3 Plot of first two factors from second discriminant analysis. Analysis on selected variables (SFINE, CSF, REG, PITTING) describing grains from all six channels. Varimax rotation on 2 factors.

In the third discriminant analysis, the data set is restricted to the four Valdez Creek Mine paleochannels. This restriction permits the weight, length, width, and thickness variables to be used. IFINE and DELTA are not used because of the missing cases. Thus, there are 9 dependent variables, which are CSF, REG, PITTING, WT, LG, WTH, TH, SPHERE, and SFINE, and the analysis is performed on 29 grains from 4 channels. The results of the third analysis can be found in Figure 15-4. The first factor was significant with a greater than 99.9% confidence level. This factor has a strong positive loading on surface gold fineness (0.522) and lesser negative loadings on thickness (-0.477), sphericity (-0.440), and CSF (-0.341). Factor 2 is not significant with a confidence level of 86% and has a strong negative loading on regularity (-0.555). The channels show the same trend as with the other two analyses: A Bench is at one extreme and the channels are in order with A Channel, B-Pl Channel, and then Tammany Channel.

Table 15-4 Rotated canonical loadings on first 2 factors from third discriminant analysis (nine dependent variables and the four Valdez Creek Mine channels only).

	FACTOR 1	FACTOR 2
CSF	-0.341	-0.026
REG	-0.210	-0.555
PITTING	-0.020	-0.267
WT	-0.143	-0.137
LG	0.003	-0.007
WTH	-0.244	-0.288
TH	-0.447	-0.182
SPHERE	-0.440	-0.044
SFINE	0.522	-0.063

In all three analyses, one factor is very highly correlated with the gold content of the surface of the gold grains (Figure 15-2 - Factor 2, Figure 15-3 - Factor 2, Figure 15-4 - Factor 1). This factor represents chemical weathering. Since the amount of weathering that a grain suffers is a function of time, grain surface gold content can be used as relative dating tool. The relative age of the channels, as indicated by the grain surface gold content, is in good agreement with the known geology, with the exception of B-Pl Channel. The relative ages of the channels are discussed further in Section 16.2.

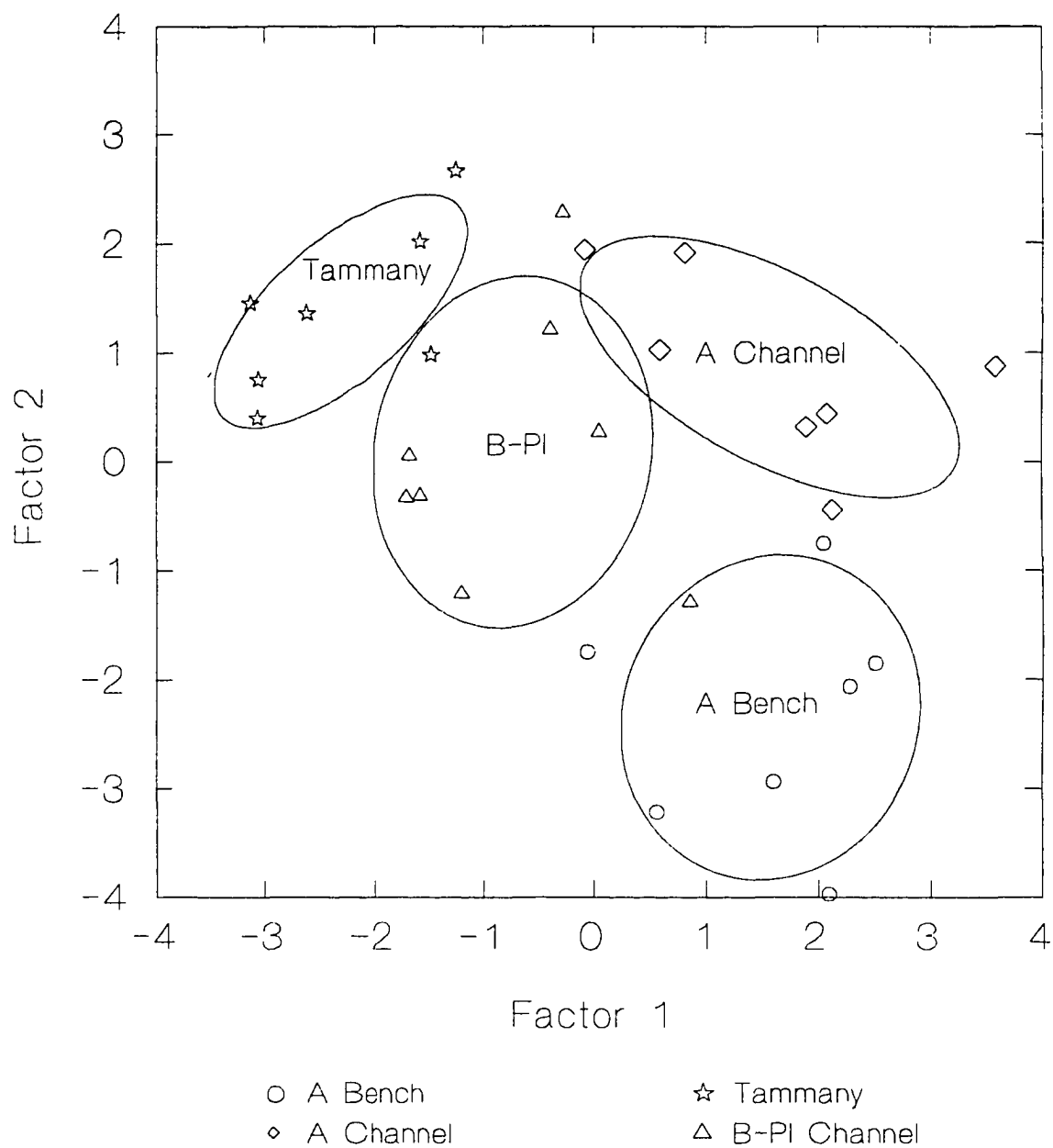


Figure 15-4 Plot of first two factors from third discriminant analysis. Analysis on selected variables (SFINE, CSF, REG, PITTING, WT, TH, LG, WT, SPHERE) describing grains from the four Valdez Creek Mine channels only. Varimax rotation on 2 factors.

The other factor (Figure 15-2 - Factor 1, Figure 15-3 - Factor 1, Figure 15-4 - Factor 2) is correlated with shape variables (CSF, REG, SPH) and appears to represent transport distance. The samples from Lucky Gulch and White Creek, collected relatively near possible bedrock sources, plot at one end of the factor. The samples from the A Bench, A Channel, B-PI Channel, and Tammany Channel were all collected from the same segment of the paleochannel system at the Valdez Creek Mine. The distance from possible sources is approximately the same for the grains collected from these channels. These channels correspond to the middle and positive end of the factor. The large spread in the position of samples from White Creek is in agreement with the observation of two populations of grains at White Creek, which are 1) chunky and irregular and 2) flat and regular. The latter are similar in appearance to grains from the Valdez Creek Mine paleochannels.

15.4. CLUSTER ANALYSIS

A K-means cluster analysis was performed on the data from all of the channels to see whether there are any other significant groupings in the data. The obvious problem with using the channels as the grouping variable is the cross-cutting nature of the channels, which leads to pirating of gold by younger channels and possible obscuring of significant factors. Also, some factors--for example, bedrock composition of gold grains--may be independent of the channel in which the grain is ultimately deposited. The K-means cluster analysis iteratively assigns cases (grains) to different clusters until a combination with the least variance is obtained. It, therefore, is ideal for finding any underlying structure hidden by the channel grouping of the grains. The micro-computer program SYSTAT (1992) was used for this analysis.

All of the seven non-size variables (CSF, SPHERE, REG, PITTING, IFINE, SFINE, DELTA) were used in this analysis. The size variables were not used in the analysis, because of the sampling method dependent problems discussed earlier (Chapter 10). K-mean clustering is not sensitive to missing values (*i.e.*, it uses cases with missing data), so IFINE and DELTA were included in the analysis. Separate analyses were performed for two to eight cluster groupings. The five cluster grouping of the data was judged to be the best because it resulted in the highest confidence level for each variable in univariate F tests that tested whether that variable was equal in all clusters (all variables were different in at least one cluster at a confidence level of greater

than 99.5%). The five cluster grouping was then saved in the data file as a variable named **CLUSTER**. A discriminant analysis was performed as in Section 15.3, using **CLUSTER** as the independent and categorical variable, and the seven non-size variables (**CSF**, **SPHERE**, **REG**, **PITTING**, **IFINE**, **SFINE**, **DELTA**) as the dependent variables. The effect of **CLUSTER** was then tested, using a Varimax rotation on three canonical variables, and then the canonical scores were saved as the **FACTORS**. Finally, the **FACTORS** were plotted, in order to visualize the results and to aid in interpretation.

The discriminant analysis indicated that there were three significant factors controlling the five cluster grouping of the data. Each of the three factors is significant at the greater than 99.5% confidence level. The rotated factors are shown in Figure 15-5 and Table 15-5. Factor 1 represents shape and has heavy loadings on **CSF** (0.798) and sphericity (0.653). Flat grains plot on the negative end of the Factor 1 axis, and chunkier grains plot on the positive end. Factor 2 represents surface characteristics, with heavy loading on pitting (0.568), regularity (0.504), and surface gold content (0.468). Regular, heavily pitted grains with high surface gold contents plot at the positive end of the Factor 2 axis. Factor 3 represents the inherited gold content of the interior of the grains, with strong positive loading on the interior gold content of the grains (0.827) and negative loading on the change in gold content between the interior and the surface of the grains (-0.734). Grains with high interior gold contents plot at the positive end of the Factor 3 axis.

Cluster 1 plots in the negative (flat) end of Factor 1 and the positive end of Factor 2. This cluster contains the majority of the A Bench and A Channel grains, as well as half of the B-P1 Channel grains. This quadrant contains the mature grains in the study. Cluster 2 plots in the opposite quadrant, where Factor 1 is positive (chunky grains) and Factor 2 is negative. Cluster 2 contains half of the B-P1 Channel grains, most of the Tammany Channel grains, most of the Lucky Gulch grains, and part of the White Creek grains. This quadrant contains the younger, less mature gold grains. Based on this distribution, it can be concluded that in this environment a mature gold grain is flat, regular, heavily pitted, and has a high gold content at the surface of the grain. Conversely, an immature grain is more spherical than flat, is irregular in shape, has less pitting, and has less gold (more silver) at the surface of the grain.

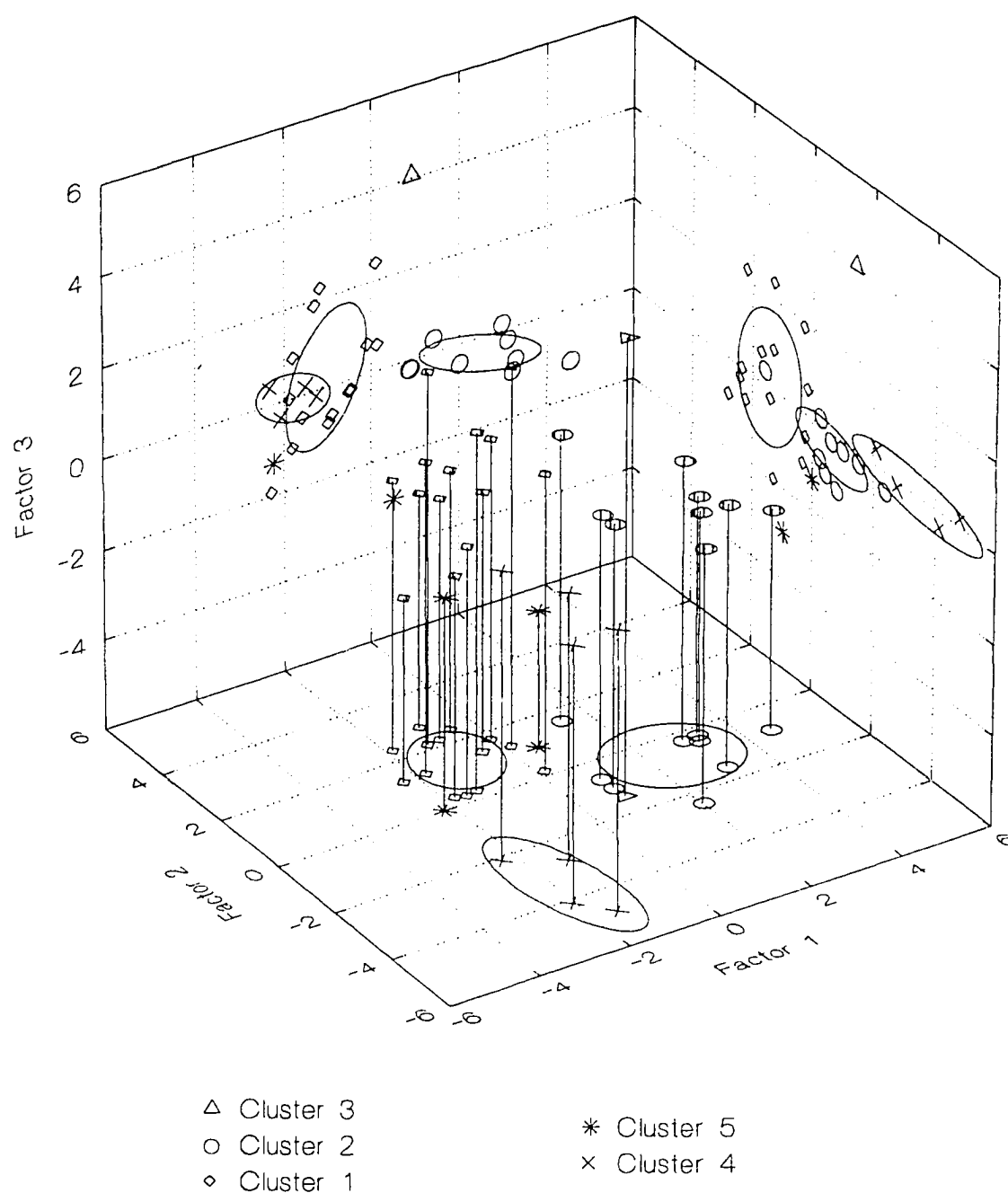


Figure 15-5 Discriminant analysis plot of Clusters using IFINE, SFINE, DELTA, SPHERE, REG, PITTING, and CSF from grains from the entire study area.

Table 15-5 Rotated canonical loadings on first 3 factors from discriminant analysis that uses the five Clusters as the grouping/categorical variable (seven dependent variables and 40 grains from all six channels).

	FACTOR 1	FACTOR 2	FACTOR 3
CSF	0.653	-0.257	-0.134
SPHERE	0.798	0.047	0.141
REG	0.086	0.504	-0.377
PITTING	-0.065	0.568	-0.036
IFINE	0.002	0.131	0.827
SFINE	-0.112	0.468	0.025
DELTA	-0.041	0.256	-0.734

These two factors indicate that the shape of the gold grains and the surface characteristics of the grains result from independent processes. Surface gold content and pitting of the grains are chemically controlled, indicating that Factor 2 represents chemical weathering. If this interpretation of Factor 2 is valid, the regularity of the gold grains results more from chemical weathering than from mechanical weathering. The shape of the gold grains is a result of mechanical weathering, indicating that Factor 1 represents mechanical weathering. Gold grains in this environment are flat when mature, which is the opposite of silicate grains. It has also been suggested that flattened gold grains are the result of glacial transport (Averill, 1988).

Factor 3 is the inherited gold content of the interior of the gold grains. Clusters 1, 2, and 4, which contain the majority of the grains, plot in the middle of this factor (they have average interior gold contents). Cluster 3 apparently contains the high Au fineness subpopulation, and Cluster 5 contains the low Au fineness subpopulation of grains noted in Chapter 15. The lack of change in the interior fineness over time (time is represented by both Factors 1 and 2) indicates that the mean gold content of the bedrock source area for the placer gold was apparently uniform spatially. However, as suggested previously, it appears there is a spatial change in the variability in the gold content of the bedrock source. Although the source had a uniform average gold fineness, apparently parts of the source had a wide range of gold finenesses, while the majority of the deposit had a narrow range of gold finenesses.

The cluster analysis identified three underlying factors controlling the characteristics of the gold grains. These factors are mechanical weathering (seen in the sphericity of the grains), chemical weathering (seen in nature of the surface of the grains), and the inherited gold

composition (of the interior of the grains). The first two factors can be used to judge the relative age of gold grains from different parts of the deposit.

16. DISCUSSION AND CONCLUSIONS

The previous chapters, analyzing the placer gold grains from Valdez Creek, began with an analysis of the sampling methods and showed that samples collected by reverse circulation drilling were significantly lighter than samples collected by hand in the same area. However, there was no difference in the shape expressed as Corey shape factor (CSF). It was also found, as expected, that the size of the grain (length, width, and thickness) is correlated with weight. Therefore, it was concluded that only gold grains collected by the same method could be statistically compared using weight, or the correlated variables length, width, and thickness. These four variables could be used only in comparing the Valdez Creek paleochannels in the Valdez Creek Mine area (A Bench, A Channel, B-Pl Channel, and Tammany Channel). Other variables, not correlated with weight, could be used in comparing the gold grains regardless of sampling method.

In the previous chapters, it has been shown that gold grains from different channels are distinct based on CSF and regularity, two variables that may be controlled by mechanical weathering. When the surfaces of the grains were examined under high magnification, etch pits were found to be a ubiquitous feature, though efforts to describe them quantitatively were unsuccessful. "Macro pitting", which is seen at lower magnification and gives a typical frosted appearance to the grains, was also described and found to vary significantly between channels. The gold in the outer 0.4 μm thick surface of the gold grains was shown to be much purer gold than that in the interior of the gold grains. It was also shown that the Au content of the surface of the gold grains varies systematically with the assumed relative ages of channels (with one exception), though there is no significant difference in the gold concentration of the interior of the gold grains between channels. The existence of etch pits in the gold grains demonstrates that the gold is oxidizing; therefore, it is concluded that the high gold content at the surface of the gold grains is due to oxidation, which would cause preferential leaching of silver and other impurities from the surface of the gold grain.

Multivariate statistics were then used to discover any underlying factors that might control the various observations in the preceding chapters. Three different discriminant analyses were performed using the source of each gold grain (the channel from which it was collected) as the

independent/categorical variable, with different combinations of dependent variables and channels.

All three analyses showed that one factor is influenced predominantly by the gold content of the surface of the grains. It was suggested that this factor represents chemical weathering of the gold grains. The second factor in the analyses is influenced predominantly by CSF, regularity, and sphericity (when sphericity was used in the analysis). It was concluded that the second factor is controlled by transport distance and therefore represents mechanical weathering.

The final multivariate test was a cluster analysis followed by a discriminant analysis. This analysis was performed in order to discover any factors that might be obscured by the use of the channels as the independent/categorical variable. The cluster analysis indicated that five groups (or clusters) of grains best describe the gold grain population. The discriminant analysis performed using the cluster grouping as the independent/categorical variable indicated that there are three significant factors controlling the clustering. Factor 1 is influenced most strongly by the shape variables, CSF and sphericity, and represents mechanical weathering. Factor 2 is influenced most strongly by pitting, regularity, and the gold content of the surface of the gold grains and represents chemical weathering. Factor 3 is influenced most strongly by the gold content of the interior of the gold grains and the change in gold content between the interior and the exterior of the gold grains. Factor 3 represents the inherited gold content of the grains (gold concentration inherited from the bedrock source). These results are consistent with the initial discriminant analyses, with the exception of regularity. Regularity, a variable defined in this study, appeared to be a mechanically controlled feature in the initial discriminant analyses, while in the cluster analysis, it appeared to be a chemically controlled feature. The cluster analysis identified the inherited gold content of the grains as a significant factor that was obscured by the channel grouping of the grains.

The chemical weathering of the gold grains will be discussed more fully below. Then the observations and conclusions presented above will be applied to some of the existing geologic problems in the Valdez Creek area.

16.1. CHEMICAL WEATHERING OF GOLD GRAINS

A number of lines of evidence have been presented which lead to the conclusion that the gold grains in the Valdez Creek drainage are corroding. Etch pits were discovered on the gold

grains; the surfaces of the gold grains were found to have a much higher gold content than the interiors of the grains; and finally, it was shown that the relative age of the grains can be found by evaluating either the mechanical weathering or the chemical weathering of the gold grains. The chemical weathering includes pitting of the grain surface and an increase in the gold content of the grain surface, both of which are due to corrosion. Corrosion of the gold grains is an oxidation dominated process. Therefore, elements in the gold grain that have a lower oxidation potential tend to go into solution first. Indeed, there is a high negative correlation between the gold content of the interior of the grains and the change in gold content between the interior and the surface of the grains. The negative correlation indicates that the correlation is actually with silver content, the dominant impurity in the gold grains. Finally, if the gold grains are corroding, i.e. weathering, the process is a function of time. The mean grain surface gold content of each channel is significantly different. The trend in mean grain surface gold content is from A Bench through A Channel, B-Pl Channel, Lucky Gulch, Tammany Channel, and finally to White Creek. This trend is largely in agreement with the previously established channel sequence, but redefines the relative age of the B-PL Channel (see next section). Hence, the amount of weathering suffered by gold grains in creeks such as Valdez Creek, where the gold grains are corroding, can be used as a relative dating tool.

Why is gold in Valdez Creek corroding, while gold in some creeks cited by other authors appears to be experiencing accretion through deposition of gold from solution? In some of those studies, the data show a difference in fineness between the surface of the gold grains and the interior of the grain, but there are insufficient data to determine the cause of this difference. Rims were thought to have been found in cross sections of grains at an early stage of this study (quantitative analysis of sections through SEM-EDS analysis), but were later determined to be artifacts related to edge rounding during polishing of the cross section of the grain. It may be that some other investigators experienced similar difficulties. However, I was suspicious of the apparent rims because I could not see a corresponding area of higher reflectance under reflected light (see Eales, 1967, for a discussion of the problems of determining gold fineness based on reflectivity). A number of authors clearly have corroborating data (quantitative analysis and reflectance) showing high fineness rims on gold grains, and their data can be accepted.

What is the difference, then, between Valdez Creek and other streams with corroding gold and streams with accreting gold? It is the oxidation/reduction regime. At Valdez Creek the geochemical environment is oxidizing and at streams with accreting gold the environment is reducing. However, for there to be gold deposition, the gold must first have gone into solution. Therefore, the streams with accreting gold must have oxidizing conditions in their upper reaches and then become reducing at some point downstream. Roll-front uranium deposits are an example of a similar oxidation/reduction-controlled ore-forming regime.

Near-surface groundwater typically becomes more reducing because of numerous oxygen sinks, such as iron-bearing minerals, buried organics, and microbial activity. Many of the streams that apparently have accreting gold are in the subArctic, where organics decompose slowly and tend to accumulate in the sediment. Also, many gold-bearing streams have a high pyrite content, a strong oxygen sink. Possibly, the key factor for a strong oxidizing regime is an alpine environment. There tends to be relatively little undecomposed organic material deposited in alpine sediments because of the very low organic productivity of alpine environments. Therefore, in drainages with little pyrite or other ferrous minerals, meteoric water may remain oxidizing after it has reached the near-surface aquifer. When the groundwater reaches lower parts of a long valley, where there are more organics in the sediment, the chemical regime would become more reducing and gold would precipitate. A similar change in geochemical environment would occur if a tributary brings in ferrous minerals. One or both of these conditions may apply to many of the streams studied by authors who found accreted gold in the non-alpine portion of the streams. At Valdez Creek, the paleochannels are in the sub-alpine area, and are deeply buried in glacial sediment that was deposited when little vegetation was present in the valley. Indeed, there is very little organic material in the alluvium or in the glacial drift that covers it; therefore, the groundwater has remained oxidizing, causing corrosion of the gold grains. One might expect that the gold that has gone into solution in the Valdez Creek drainage has precipitated somewhere downstream in the Susitna valley.

16.2. RELATIVE AGE OF CHANNELS

In all the three discriminant analyses and in the cluster analysis, one factor is very highly correlated with the gold content of the surface of the gold grains (Figure 15-2 -- Factor 2, Figure

15-3 -- Factor 2, Figure 15-4 -- Factor 1, Figure 15-5 -- Factor 2). This factor represents chemical weathering. Since the amount of weathering that a grain suffers is a function of time, grain surface gold content can be used as relative dating tool. The relative ages of the channels indicated by grain surface gold content is largely in accord with the previously assumed chronology. A Bench, with the highest Au fineness, is the oldest; the A Channel is incised into the A Bench and therefore must be younger; the Tammany Channel is also incised into the A Bench and has been observed to have pirated gold from the A Channel/A Bench (Teller, 1989). The White Creek placer is the youngest deposit, probably Pleistocene, pre-dating the Hatchet Lake Glaciation. White Creek samples, however, occupy a large range in this dimension (that is, they display a large range in surface fineness), suggesting that some of the grains may have been recycled from an older deposit. This suggestion is compatible with the qualitative observation of two distinct types of grains in this deposit.

Lucky Gulch grains occupy an intermediate position that is off the main trend. This suggests that grains in Lucky Gulch have been subjected to somewhat different conditions than other grains. The gold in the Lucky Gulch placer may have weathered differently from that in the other channels because of such factors as lower groundwater flow, higher elevation, and shallower depth of burial, which may have resulted in a different groundwater chemistry than in the other Valdez Creek channels.

The remaining channel, B-Pl, is in a surprising position. What is known of this channel is two meander remnants, B and Pl. This channel has previously been interpreted as the oldest channel, but its discriminant score suggests that it is younger than the A Bench and possibly younger than the A Channel, but probably older than the Tammany Channel. Thus, the relative age of the channels, from oldest to youngest (based on gold grain characteristics) is A Bench, A Channel, B-Pl Channel, Tammany Channel, and White Creek. Although off trend, the Lucky Gulch placer appears to be about the same age as the B-Pl Channel.

Numerous lines of evidence, in particular the discriminant analyses and the fineness of the interior and surface of the gold grains, indicate that the B-Pl Channel is younger than previously thought. The B-Pl Channel was previously considered to be the oldest channel, based on the relative elevation of the channels, the two remnants of the B-Pl Channel being shallower than any

of the other channels. The reasoning used to assign relative ages to the channels based on their relative depth assumes that each erodes to a given depth determined by external factors, such as gradual regional uplift or gradual lowering of the local base level. I think the reason the depths of the A system and the B-Pl Channel are reversed is that the A system is much more mature than the B-Pl Channel. The A Bench represents a very broad, nearly valley-wide channel that probably existed for a very long time. The A Channel is also a broad, well developed channel that can be traced well up-valley. The B-Pl Channel probably developed over a shorter period of time and, therefore, did not reach the same depth as the A Bench and Channel. Another factor that would affect the depth of a channel is the position of the Susitna River. If one considers the depth of two channels, the channel graded to a Susitna River located on the west side of its valley would be shallower (B-Pl?) than the channel graded to a Susitna River located on the east side of its valley (e.g., the A system?), all other factors being equal.

16.3. TIME-STRATIGRAPHIC INTERPRETATION

Combining the relative ages of the channels and the geomorphic evidence, it is possible to draw tentative conclusions regarding the age of the Valdez Creek channels relative to the regional glacial chronology. Given the current difficulties in correlating glacial sequences in Alaska and northwest Canada (Brigham-Grette, 1989; Hughes, 1989), it is not possible to reach any firm conclusions, but some reasonable alternatives are presented.

The oldest channel, the A Bench and the A Channel that is eroded into it, must be younger than the high level surface. This surface was formed by the Clearwater Glaciation of this thesis. I believe this glaciation is correlative to the Teklanika Glaciation of Thorson (1986) in the Nenana valley and the Darling Creek Glaciation of Péwé (1961, 1965, 1975) in the Amphitheater Mountains and in the Delta River valley. This glaciation probably occurred near the Pliocene/Pleistocene boundary (Péwé, 1961, 1965, 1975; Thorson, 1986). The next major glacial event was probably mid-Early Pleistocene and is referred to as the Browne Glaciation in the Nenana Valley chronology (Wahrhaftig, 1958; Péwé, 1975; Thorson, 1986). I suggest that the Craig Glaciation of this thesis is equivalent to the Browne Glaciation, and that the A system (channel and bench) formed during the interglacial between the formation of the high level surface (Clearwater Glaciation) and the mid-Early Pleistocene Craig Glaciation. Assuming that each

paleochannel represents an interglacial period, then the B-Pl Channel probably formed during the next interglacial, prior to the Dry Creek Glaciation (Wahrhaftig, 1958; Péwé, 1975) or the age equivalent Bear Creek Glaciation (Thorson, 1986) in the Nenana valley. No record of this glaciation is recognized in the Valdez Creek valley, although evidence is seen elsewhere in the Clearwater Mountains. Lucky Gulch has evolved somewhat differently than the other Valdez Creek channels, but appears to be time equivalent to the B-Pl Channel and, therefore, is assigned to this interval. The Tammany Channel was formed in the next interglacial, prior to the Lignite Creek Glaciation in the Nenana valley (Thorson, 1986). Recent correlations by Hughes (1989) have placed the Delta Glaciation in the Delta River area in the Illinoian, which would be equivalent to the Lignite Creek Glaciation. No geomorphic evidence of an equivalent Illinoian Glaciation has been recognized in the Valdez Creek valley. Finally, the White Creek placer is thought to be pre-Wisconsinan (early Sangamon), occurring after the Lignite Creek equivalent and prior to the early Wisconsinan Glaciation represented by the Healy Glaciation in the Nenana Valley (Thorson, 1986), the Denali I Glaciation in the Amphitheater Mountains (Péwé, 1956, 1961, 1975; West, 1975, 1981; and Schweger, 1981), the Donnelly Glaciation (?) in the Delta River area (Péwé, 1961, 1965, 1975; Hughes, 1989). The Smith Channel, which was not studied in this thesis, may be the paleochannel in Valdez Creek proper that is equivalent to the White Creek placer. (Evidence of Smith Channel becomes obscure near the upstream intersection with the A Channel [Figure 8-1]. The cross-cutting relationship is undocumented.)

This chronology works well, in that it parallels periods of significant incision observed by Thorson (1986) in the Nenana River area. However, this chronology assumes that there is some climatic significance to the interglacial periods that resulted in more incision than during interstadials, even though the latter may be equivalent or longer. The potential problem is that the Boutellier (Wisconsinan interstadial) appears to have been longer than the Sangamon interglacial (there was probably one or possibly two glacial episodes that punctuated the Sangamon interglacial [Vincent, 1989].)

If the amount of channel development (up-valley extent, width) is more simply a function of the time available for down-cutting, i.e., the length of the interglacial/interstadial period, then the youngest channels (White Creek Placer and Smith Channel[?]) were probably formed during the Wisconsinan interstadial. This reasoning would put the Tammany Channel as pre-early

Wisconsinan/late Sangamon (pre-Healy and post-Lignite Creek), and would suggest that no channel formed during the early Sangamon interglacial (pre-Lignite Creek and post-Bear Creek), which was apparently only 10 ky long, as compared to the approximately 40 ky of the late Sangamon and Wisconsinan interstadials.

The final possibility that I will discuss is that the formation of the A Bench and A Channel did not follow immediately after the Clearwater Glaciation, but formed in the last pre-Illinoian interglacial, with each channel being formed in each of the successive, recognized interglacial/interstadial periods. This alternative has the advantage of meshing well with the Thorson's glacial chronology in the Nenana River and of having a one-to-one correspondence between paleochannels and recognized interglacial/interstadial periods. However, it has the disadvantage of leaving unexplained the long period between the Clearwater Glaciation and the last pre-Illinoian Glaciation.

I prefer the second alternative. First, I think the Clearwater Glaciation, represented by the remnants of the high level surface, is indeed very old. I think further work will trace this surface to the east and establish that it comprises remnants of the same surface found in the Amphitheater Mountains and, thus, that the Clearwater Glaciation is correlative to the Darling Creek Glaciation. This surface can be traced to the west, but tracing it north across the Alaska Range to areas with preserved features of the Teklanika or Browne Glaciations will be much more difficult. Second, I think it took longer than 10 ky to create one of the paleochannels, based on the amount of Holocene incision of the modern Valdez Creek channel. Using the chronology proposed by the joint Canadian-American workshop on the late Cenozoic history of the interior basins of Alaska and the Yukon (Vincent, 1989), the early Sangamon (122-132 ka) was only 10 ky long and, therefore, was not long enough to have developed a preserved paleochannel. Thus, the Clearwater Glaciation is Plio/Pleistocene; the A Bench and A Channel were formed during a prolonged Early Pleistocene interglacial; the Craig Glaciation was a mid-Early Pleistocene Glaciation, followed by formation of the B-Pl Channel (and Lucky Gulch?) during the last pre-Illinoian interglacial; no channel was formed during the early Sangamon; the Tammany Channel was formed during the late Sangamon interglacial; and the White Creek placer (and Smith Channel?) was formed during the mid-Wisconsinan interstadial, followed by the late Wisconsinan Hatchet Lake Glaciation and the Holocene Eldorado Creek Glaciation. Péwé still thinks the Browne Glaciation may be two my old

(Matthews, 1989); whereas Reger and Bundtzen (1990) correlate the Brown/pre-Browne Glaciation with the Darling Creek Glaciation and consider them simply as pre-Illinoian; and Hughes (1989) considers the Darling Creek to be late-Early Pleistocene. Based on the correlation of the Browne/pre-Browne Glaciations and the Darling Creek Glaciation, and the argument that it took longer than 10 ky to form a Valdez Creek paleochannel, a late age for Darling Creek Glaciation is problematic. In order to have an adequate number of sufficiently long nonglacial periods, the Clearwater, Browne, and Darling Creek Glaciations must be at least mid-Early Pleistocene or Plio/Pleistocene. For these reasons, I think the A Channel is very old, probably Early Pleistocene, but at least late pre-Illinoian, which is considerably older than the Sangamon age preferred by Reger and Bundtzen (1990).

16.4. INFERENCES ABOUT THE LODE SOURCE

Once the relative ages of different parts of a deposit have been determined, the fineness of the interior of the grains can be interpreted. It is shown in Section 14.3 that there are three subpopulations of gold grains (based on the fineness of the interior of the grains), but that these subpopulations are not evident as significant differences in the mean gold fineness of the interiors of gold grains from one channel to another (see Figure 14-3, page 94). There is, however, a trend in the variability of the gold content of the interior of the gold grains with time, such that the older channels have more variability than the younger channels. The B-Pl Channel lies between the A Channel and the Tammany Channel in this trend. The relative ages of the channels have been established by various lines of evidence, which show that a relative age sequence placing the B-Pl Channel between the A Channel and the Tammany Channel is correct.

Based on the assumptions that (1) erosion progressed downward and to the south from an ancestral drainage on the high level surface and (2) that the gold content of the interior of the grains is inherited from the bedrock source, it can be concluded that the bedrock source(s) of gold in Valdez Creek had spatial zoning in the upper or northern part of the deposit and that the later eroded, deeper or southern source(s) was not zoned and showed a marked decrease in variability in the free gold fineness.

This might be explained if ascending fluids altered the country rock. The fluids reaching distal parts of the system would have evolved to varying degrees, depending on the nature of the

wall rock contacted in transit. Fluids that deposited their gold in more proximal parts of the system would be buffered by the more homogenous rock previously altered by the passage of earlier fluids.

A source with the distal portion in the Gold Hill/Lucky Hill area and the proximal portion in the White Creek drainage would explain the pattern observed. The old channels (A Bench and Channel) contain gold initially eroded from the distal (upper/northern) part of the deposit. As erosion progressed downward/south, gold was eroded almost exclusively from the main unzoned part of the deposit (Subpopulation 2) and deposited in the B-Pl Channel. Gold continued to be eroded from remnants of the zoned part of the deposit (distal--upper\north) and was deposited in Lucky Gulch. Erosion continued downward/south into more proximal parts of the deposit, which contained free gold, with less variability in its fineness, that was then deposited in Tammany Channel and White Creek (and presumably Smith Channel). A single source is described, but multiple genetically related sources could also show the same pattern.

16.5. FURTHER WORK

Etch pits have been documented in the gold grains of this study. Unfortunately, I was unable to quantify them as a variable in this work. The etch pits seem to have much potential as a relative dating tool, if they could be quantified. A few gold grains should be studied at a variety of magnifications, particularly at magnifications greater than 400x, in order to determine the absolute size range and the size distribution of the etch pits. I also suspect that there is considerable variation from one part of a grain to another, which would need to be evaluated.

The average fineness of the gold grains in this study is different from the average fineness of the gold in Valdez Creek reported in other sources. What is the source of this difference? Does the fineness of the gold at this deposit vary by size fraction? Are the conclusions of this study dependent on the size fraction analyzed, or are they independent of the size fraction?

How thick is the high fineness rim on the gold grains? Does it vary with age? Can the thickness of the rim be used for relative dating? Auger Electron Spectroscopy (AES), as used by Mogk and Locke (1988), may be useful.

Although many of the reports of gold precipitation on placer gold grains are poorly documented in the literature, a few seem to be reliable. It was suggested in this study that leaching

or precipitation may be controlled by climatic/biologic zoning, with leaching occurring in areas of low organic content sediment, such as alpine and sub-alpine areas, and precipitation occurring in lower elevation areas with more organic-rich sediment. A rigorous study of gold from a deposit in a low elevation stream in interior Alaska might document gold precipitation on gold placer grains. A study of gold from a stream that traverses these environments (alpine/sub-alpine to lowland) might find both gold leaching and precipitation.

The surficial geology in this study is largely based on aerial photo mapping. Soils mapping and quantitative geomorphology could be used to refine this work. I observed tephra layers in some of the soil pits I dug, indicating that there may be potential for using tephrochronology for age control.

The Valdez Creek Mine is nearing the end of its mine life. A database of over a thousand drill holes may become available for use in three dimensional modeling of this dynamic glacial environment. At present, the data are only partially computerized. This would be a very large project, requiring sophisticated computing software and hardware.

17. REFERENCES

- Ashley, G.M., Shaw, J., and Smith, N.D., 1985, Glacial sedimentary environments: Society of Economic Paleontologists and Numerologists Short Course No. 16, 246 p.
- Averill, S.A., 1988, Regional variations in the gold content of till in Canada *in* MacDonald, D. R. and Mills, K. A., eds., International symposium on prospecting in areas of glaciated terrain, 8th, Halifax, Nova Scotia: Proceedings: Canadian Institute of Mining and Metallurgy, p. 271-284.
- Baker, W.E., 1978, The role of humic acid in the transport of gold: *Geochimica et Cosmochimica Acta*, v. 42, p. 645-650.
- Benedetti, Marc, and Boulègue, Jacques, 1991, Mechanism of gold transfer and deposition in a supergene environment: *Geochimica et Cosmochimica Acta*, v. 55, p. 1539-1547.
- Berner, R. A., Sjöberg, E.L., Velbel, M.A., and Krom, M.D., 1980, Dissolution of pyroxenes and amphiboles during weathering: *Science*, v. 207, p. 1205-1206.
- Berner, R.A., and Schott, J., 1982, Mechanism of pyroxene and amphibole weathering II. Observations of soil grains: *American Journal of Science*, v. 282, p. 1214-1231.
- Bowen, H.J.M., 1985, The cycles of Cu, Ag, and Au, *in* O. Huttinger, ed., The natural environment and the biogeochemical cycles, *in* the collection The Handbook of Environmental Chemistry: Springer-Verlag, Bayreuth, Germany, p. 1-27.
- Brantley, S.L., Crane, S.R., Crerar, D. A., Hellmann, R., and Stallard, R., 1986, Dissolution at dislocation etch pits in quartz: *Geochimica et Cosmochimica Acta*, v. 50, p. 2349-2361.
- Bressler, J.R., Jones, W.C., and Cleveland, Gaylord, 1984, Geology of a buried channel system at the Denali placer gold mine: Alaska Miner's Association Abstracts.
- Brigham-Grette, J., 1989, Geochronology, *in* Carter, L.D., Hamilton, T.D., and Galloway, J.P., eds., Late Cenozoic history of the interior basins of Alaska and the Yukon: U.S. Geological Survey Circular 1026, p. 107.

- Clifton, E.H., Hunter, R.I., Swanson, F.J., and Phillips, R.L., 1969, Sample size and meaningful gold analysis: U.S. Geological Survey Professional Paper 625-C, p. C1-C17.
- Clough, D.M., and Craw, D., 1989, Authigenic gold-marcasite associations: Evidence for nugget growth by chemical accretion in fluvial gravels, Southland, New Zealand: *Economic Geology*, p. 953-958.
- Corey, A.T., 1949, Influence of shape on the fall velocity of sand grains: Colorado A & M College (now Colorado State Univ.), Fort Collins, unpublished Master's thesis, 102 p.
- Csejtey, B. Jr., Cox, D.P., Evarts, R.C., Stricker, G.D., and Foster, H.L., 1982, The Cenozoic Denali fault system and the Cretaceous accretionary development of southern Alaska: *Journal of Geophysical Research*, v. 87, p. 3741-3754.
- Davidson, Cameron, Hollister, L.S., and Schmid, S.M., 1992, Role of melt in the formation of a deep-crustal compressive shear zone: The MacLaren Glacier Metamorphic Belt, south central Alaska: *Tectonics*, v. 11, p. 348-359.
- Desborough, George, A. , 1970, Silver depletion indicated by microanalysis of gold from placer occurrences, western United States: *Economic Geology*, v. 65, p. 304-311.
- Dessauer, P.F., and Harvey, D.W., 1980, An historical resource study of the Valdez Creek mining district, Alaska -- 1977: Boulder, Western Interstate Commission for Higher Education (unpublished report prepared for U.S. Bureau of Land Management), 212 p.
- Eales, Hugh V., 1967, Reflectivity of gold and gold-silver alloys: *Economic Geology*, v. 62, p. 412-420.
- Folk, Robert L., 1974, Petrology of sedimentary rocks: Hemphill Publishing Co., Austin, Texas, 182 p.
- Giusti, L., 1986, The morphology, mineralogy, and behavior of "fine-grained" gold from placer deposits of Alberta: sampling and implications for mineral exploration: *Canadian Journal of Earth Sciences*, v. 26, p. 1662-1672.

- Gorshkov, L.S., Nikolaeva, L.A., and Epshtein, Y.A., 1971, Changes in gold during river and marine placer deposit formation in the Khualaztza ore field, southern Maritime Territory: *Chemical Abstracts*, v. 75.
- Groen, J.C., Craig, J.R., and Rimstidt, J.D., 1987, Gold rim formation and the enrichment of placer nuggets: *Geological Society of America Abstracts with Programs*, p. 684.
- Helgeson, H.C., Murphy, W.M., and Aagaard, P., 1984, Thermodynamic and kinetic constraints on reaction rates among minerals and aqueous solutions. II. Rate constants, effective surface area, and the hydrolysis of feldspar: *Geochimica et Cosmochimica Acta*, v. 48, p. 2405-2432.
- Hughes, O.L., 1989, Quaternary chronology, Yukon and Western District of Mackenzie, in Carter, L.D., Hamilton, T.D., and Galloway, J.P., eds., Late Cenozoic history of the interior basins of Alaska and the Yukon: *U.S. Geological Survey Circular 1026*, p. 25-29.
- Jean, G.E., and Bancroft, G.M., 1985, An XPS and SEM study of gold deposition at low temperatures on sulphide mineral surfaces: Concentration of gold by adsorption/reduction: *Geochimica et Cosmochimica Acta*, v. 49, p. 979-987.
- Jones, D.L., Silberling, N.J., Berg, H.C., and Plafker, George, 1981, Map showing tectonostratigraphic terranes of Alaska, columnar sections, and summary description of terranes: *U.S. Geological Survey Open-File Report 81-792*.
- Kachadoorian, Reuben, Hopkins, D.M., and Nichols, E.R., 1954, A preliminary report of geologic factors affecting highway construction in the area between the Susitna and MacLaren Rivers, Alaska: *U.S. Geological Survey Open-file Report*, 74 p.
- Knauss, K.G., and Wolery, T.J., 1988, The dissolution kinetics of quartz as a function of pH and time at 70° C: *Geochimica et Cosmochimica Acta*, v. 52, p. 43-53.
- Krauskopf, Konrad B., 1951, The solubility of gold: *Economic Geology*, v. 46, p. 858-870.
- Krauskopf, Konrad B., 1979, *Introduction to Geochemistry*: McGraw-Hill, New York, p. 424-426.

- Krendelev, K.B., Zhmodik, S.M., and Mironov, A.G., 1978, An Au-195 study of the sorption of gold by natural layer silicates and iron hydroxides: *Geochemistry International*, v. 15, p. 156-162.
- Lakin, H.W., Curtin, C.G., and Hubert, A.E., 1974, *Geochemistry of gold in the weathering cycle*: U.S. Geological Survey Bulletin 1330, 80 p.
- Lasaga, A.C., and Blum A.E., 1986, Surface chemistry, etch pits and mineral-water reactions: *Geochimica et Cosmochimica Acta*, v. 50, p. 2363-2379.
- Leslie, Lynn D., 1989, Alaska climate summaries -- A compilation of long-term means and extremes at 478 Alaskan stations: Alaska Climate Center Technical Note No. 5., Arctic Environmental Information and Data Center, University of Alaska Anchorage, Anchorage, Alaska, 478 p.
- Lesure, Frank G., 1971, Residual enrichment and supergene transport of gold, Calhoun Mine, Lumpkin County, Georgia: *Economic Geology*, v. 66, p. 178-189.
- Mann, A.W., 1984, Mobility of gold and silver in lateritic weathering profiles: Some observations from western Australia: *Economic Geology*, v. 79, p. 38-49.
- Matthews, J.V. Jr., 1989, Late Tertiary events, *in* Carter, L.D., Hamilton, T.D., and Galloway, J.P., eds., Late Cenozoic history of the interior basins of Alaska and the Yukon: U.S. Geological Survey Circular 1026, p. 111-112.
- Moffatt, W.G., Pearsall, G.W., and Wulff, J., 1964, *The structure and properties of materials*: John Wiley and Sons, New York, 236 p.
- Mogk, D.W., and Locke, W.W.III, 1988, Application of Auger Electron Spectroscopy (AES) to naturally weathered hornblende: *Geochimica et Cosmochimica Acta*, v. 52, p. 2537-2542.
- Morrison, G.W., Rose, W.J., and Jaireth, Subhash, 1991, Geological and geochemical controls on the silver content (finesness) of gold in gold-silver deposits: *Ore Geology Reviews*, v. 6, p. 333-364.

- Nokleberg, W.J., Jones, D.L., and Silberling, N.J., 1985, Origin and tectonic evolution of the MacLaren and Wrangellia terranes, eastern Alaska Range, Alaska: *Bulletin of the Geological Society of America*, v. 96, p. 1251-1270.
- Petrovic, R., Berner, R.A., and Goldhaber, M.B., 1976, Rate control in dissolution of alkali feldspars—I. Study of residual feldspar grains by X-ray photoelectron spectroscopy: *Geochimica et Cosmochimica Acta*, v. 40, p. 537-548.
- Péwé, T.L., 1961, Multiple glaciation in the headwaters area of the Delta River, central Alaska, *in* Short papers in the geologic and hydrologic sciences 1961: U.S. Geological Survey Professional Paper 424-D, p. D200-D201.
- Péwé, T.L., 1965, Delta River area, Alaska Range, *in* Péwé, T.L., Ferrians, O.J., Jr., Nichols, D.R., and Karlstrom, T.N.V., Guidebook for field conference F, central and south-central Alaska, International Association for Quaternary Research, 7th Congress, Fairbanks, 1965: Nebraska Academy of Sciences, Lincoln, Nebraska (reprinted 1977, Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska), p. 55-93.
- Péwé, T.L., 1975, Quaternary geology of Alaska: U.S. Geological Survey Professional Paper 835, 145 p.
- Péwé, T.L., and Holmes, G.W., 1964, Geology of the Mt. Hayes (D-4) Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-394, scale 1:63,360, 2 sheets.
- Potts, P.J., 1987, A handbook of silicate rock analysis: Blackie, 622 p.
- Powers, M.C., 1953, A new roundness scale for sedimentary particles: *Journal of Sedimentary Petrology*, v. 23, p. 117-119.
- Reger, R.D., and Bundtzen, T.K., 1990, Multiple glaciation and gold-placer formation, Valdez Creek valley, Western Clearwater Mountains, Alaska: Alaska Division of Geological and Geophysical Surveys, Professional Report 107, 29 p.
- Ritter, D.F., and Ten Brink, N.W., 1982, Paraglacial fan formation and glacial history, Nenana Valley, Alaska: *Journal of Geology*.

- Ross, Clyde P., 1933, The Valdez Creek Mining District, Alaska: U.S. Geological Survey Bulletin 849-II, p. 425-468.
- Sakharova, M.S., 1969, Mineralogy of Darasun gold field in eastern Transbaikalia: International Geologic Review, v. 11, p. 45-59.
- Sakharova, M.S., and Demidov, V.G., 1972, Gold to silver ratio in the Darasun deposit: Chemical Abstracts, v. 77.
- Schweger, C.E., 1981, Chronology of late glacial events from the Tangle Lakes, Alaska Range. Alaska: Arctic Anthropology, v. 18, p. 97-110.
- Smith, P.S., 1941, Fineness of gold from Alaska Placers: U.S. Geological Survey Bulletin 910-C, 272 p.
- Smith, Thomas E., 1970, Gold Resource Potential of the Denali Bench Gravels, Valdez Creek Mining District, Alaska: U.S. Geological Survey Professional Paper 700-D, pp. D116-D152.
- Smith, Thomas E., 1981, Geology of the Clearwater Mountains, South-central Alaska: Alaska Division of Geologic and Geophysical Survey Geologic Report 60, 72 p., 3 plates.
- Stanley, Clifford R., 1987, Probplot -- An interactive computer program to fit mixtures of normal (or log-normal) distributions with maximum likelihood optimization procedures: The Association of Exploration Geochemists, Spec. Vol. No. 14, 1 disk (640K).
- Stevens, Donald L., 1986, 1986 Exploration Program, Rowallan Mines Partnership Property, Valdez Creek, Alaska: Unpublished consultants report, 25 p.
- SYSTAT, 1992, SYSTAT for Windows, Version 5: SYSTAT, Inc., Evanston, IL.
- Teller, S.D., 1988a, The shape and weight characteristics of +20 mesh gold, A-4 Pit channel and grab samples: Unpublished consultant's report for Valdez Creek Mining Co., 41 p.
- Teller, S.D., 1988b, Gold recovery in drilling, Denali Mine, Valdez Creek Mining Co.: Unpublished consultant's report for Valdez Creek Mining Co., 55 p.
- Teller, S.D., 1989, Valdez Creek Mining Co. confidential ore reserve calculations.

- Teller, S.D., 1990, The geology and gold evolution at the Denali Mine, Valdez Creek, Alaska: The Alaska Miner, v. 18, n. 1, p. 13.
- Teller, S.D., and Bressler, J.R., 1988, Gold placer mineralization and gold weathering, Denali Mine, Valdez Creek District, Alaska, *in* Bicentennial Gold 88--Extended Abstract Poster program, v. 1: Geologic Society of Australia, Abstracts Series No. 23, p. 391-393.
- Thorson, R.M., Dixon, E.J., Jr., Smith, G.S. and Batten, A.R., 1981, Interstadial proboscidean from south-central Alaska: Implications for biogeography, geology, and archeology: Quaternary Research, v.16, p.404-417.
- Thorson, Robert M., 1986, Late Cenozoic glaciation of the northern Nenana River valley, *in* Hamilton, T.D., Reed, K.M., and Thorson, R.M., eds., Glaciation in Alaska -- The geologic record: Alaska Geological Society, Anchorage, Alaska, p. 99-121.
- Tourtelot, Harry A., 1968, Hydraulic equivalence of grains of quartz and heavier minerals, and implications for the study of placers: U.S. Geological Survey, Professional Paper 594-F, 13 p.
- Tuck, Ralph, 1938, The Valdez Creek Mining District, Alaska, in 1936: U.S. Geological Survey Bulletin 897-B, p. 109-131.
- Valdez Creek Mining Co., 1989, General Information Brochure, Denali Mine: Valdez Creek Mining Co., 4 p.
- Vincent, J-S., 1989, Late Pleistocene Glacial Advances, *in* Carter, L.D., Hamilton, T.D., and Galloway, J.P., eds., Late Cenozoic history of the interior basins of Alaska and the Yukon: U.S. Geological Survey Circular 1026, p. 111-112.
- Vlassopoulos, Dimitrios, and Wood, S.A., 1990, Gold speciation in natural waters: I. Solubility and hydrolysis of gold in aqueous solution: Geochimica et Cosmochimica Acta, v. 54, p. 3-12.
- Vlassopoulos, Dimitrios, Wood, S.A., and Mucci, Alfonso, 1990, Gold speciation in natural waters: II. The importance of organic complexing--Experiments with some simple model ligands: Geochimica et Cosmochimica Acta, v. 54, p. 1575-1586.

- Wahrhaftig, Clyde, 1958, Quaternary and engineering geology in the central part of the Alaska Range: U.S. Geological Survey Professional Paper 293, 118 p.
- Watterson, J.R., Nishi, J.M., and Botinelly, T., 1983, Evidence that gold can nucleate on bacterial spores: U.S.G.S. Circular 945, p. 1-4.
- Watterson, John R., 1985, Crystalline gold in soil and the problem of supergene nugget formation: freezing and exclusion as genetic mechanisms: *Precambrian Research*, v. 30, p. 321-335.
- Welsch, Dennis, Goodwin, Robert, and Ten Brink, Norman, 1982, Late Quaternary glaciations of the Talkeetna Mountains, Alaska [abs.]: *Geological Society of America Abstracts with Programs*, v. 14, p. 353-354.
- West, F.H., 1975, Dating the Denali Complex: *Arctic Anthropology*, v. 12, p. 76-81.
- West, F.H., 1981, *Archaeology of Beringia*: Columbia University Press, 268 p.
- WGM Inc., 1983, Report on the 1983 Exploration program, Denali Mine, Valdez Creek Mining District Alaska: Unpublished consultant's report prepared for CAMINDEX Mines., 159 p.
- WGM Inc., 1984, Report on the 1984 Denali Mine Exploration Program, Valdez Creek, Alaska: Unpublished consultant's report.

18. APPENDICES

18.1. Appendix 1. Raw data for Drilling Study (Chapter 10), +20 mesh gold grains

Appendix 1. Raw data for Drill Study (Chapter 10): +20 mesh gold grains.

TYPE	AREA	SAMPLE	GRAIN	WEIGHT	LENGTH	WIDTH	THICK	CSF
		HOLE		(mg)	(mm)	(mm)	(mm)	
HAND	1	5	36	22.5	3.00	1.86	0.53	0.224
HAND	1	5	55	10.0	1.64	1.69	0.34	0.204
HAND	1	5	56	34.8	3.29	2.37	0.55	0.197
HAND	1	5	71	19.3	1.88	1.44	0.68	0.413
HAND	1	5	78	20.0	2.36	1.73	0.59	0.292
HAND	1	11	4	8.7	1.58	1.46	0.40	0.263
HAND	1	11	20	6.7	1.50	1.32	0.32	0.227
HAND	1	11	44	49.4	3.81	2.54	0.62	0.199
HAND	1	11	48	7.1	1.68	1.26	0.35	0.241
HAND	1	11	50	14.2	2.37	1.57	0.55	0.285
HAND	1	11	54	5.5	1.81	1.34	0.30	0.193
HAND	1	11	57	30.2	2.72	2.56	0.52	0.197
HAND	1	11	58	27.9	2.71	2.30	0.48	0.192
HAND	1	11	61	20.2	2.54	2.17	0.50	0.213
HAND	1	11	62	95.4	3.63	2.95	0.90	0.275
HAND	2	1	16	26.7	3.90	1.82	0.52	0.195
HAND	2	1	23	123.2	5.12	3.20	1.27	0.314
HAND	2	1	25	123.1	6.81	3.30	0.87	0.184
HAND	2	1	37	199.2	5.80	5.71	0.84	0.146
HAND	2	1	39	93.1	4.62	3.34	0.71	0.181
HAND	2	1	41	27.0	4.14	1.85	0.42	0.152
HAND	2	1	42	58.1	4.56	2.68	0.51	0.146
HAND	2	1	51	329.4	7.59	4.72	1.57	0.262
HAND	2	1	52	55.5	4.96	2.64	0.82	0.227
HAND	2	1	68	28.0	3.71	1.82	0.71	0.273
HAND	2	4	7	26.9	3.92	2.12	0.87	0.302
HAND	2	4	18	16.7	2.44	1.94	0.42	0.193
HAND	2	4	22	39.0	3.86	2.12	0.52	0.182
HAND	2	4	34	51.6	4.24	3.62	0.55	0.140
HAND	2	4	65	23.2	3.03	2.42	0.43	0.159
HAND	2	8	12	230.4	6.78	4.16	1.56	0.294
HAND	2	8	19	1057.9	9.98	6.11	1.90	0.243
HAND	2	8	29	32.1	2.98	2.42	0.69	0.257
HAND	2	8	35	37.2	3.94	1.55	0.71	0.287
HAND	2	8	43	58.3	5.10	2.86	0.56	0.147
HAND	2	8	47	93.1	4.78	4.48	0.65	0.140
HAND	2	8	69	42.7	3.68	2.68	0.53	0.169
HAND	2	8	72	88.9	4.33	3.64	0.55	0.139
HAND	2	8	76	72.0	4.40	3.56	0.59	0.149
HAND	2	8	82	44.2	3.07	3.28	0.58	0.183

Appendix 1. Raw data for Drill Study (Chapter 10): +20 mesh gold grains.

TYPE	AREA	SAMPLE	GRAIN	WEIGHT	LENGTH	WIDTH	THICK	CSF
	HOLE			(mg)	(mm)	(mm)	(mm)	
HAND	3	6	1	35.6	2.64	2.44	0.52	0.205
HAND	3	6	8	72.3	3.63	2.30	0.82	0.284
HAND	3	6	15	147.0	4.89	3.59	0.95	0.227
HAND	3	6	45	23.4	2.34	2.33	0.48	0.206
HAND	3	6	49	424.3	8.08	5.79	1.41	0.206
HAND	3	6	60	438.3	6.25	6.05	1.22	0.198
HAND	3	6	70	138.3	3.99	3.27	1.10	0.305
HAND	3	6	75	69.6	3.71	2.98	0.63	0.189
HAND	3	7	5	30.6	3.24	1.48	0.76	0.347
HAND	3	7	9	52.0	3.18	2.01	1.01	0.399
HAND	3	7	30	16.6	2.19	1.94	0.56	0.272
HAND	3	7	31	18.7	1.82	1.50	0.74	0.448
HAND	3	7	38	21.8	2.32	1.87	0.49	0.235
HAND	3	7	59	721.5	14.10	6.45	1.49	0.156
HAND	3	7	80	254.0	5.72	5.18	1.01	0.186
HAND	4	3	6	18.6	3.23	1.59	0.39	0.172
HAND	4	3	11	94.3	5.54	3.18	0.58	0.138
HAND	4	3	17	27.9	3.71	1.66	0.53	0.214
HAND	4	3	73	155.7	7.19	3.76	0.80	0.154
HAND	4	9	24	54.2	3.35	2.30	0.70	0.252
HAND	4	9	63	79.7	4.23	2.78	0.77	0.225
HAND	4	9	77	29.6	3.83	3.02	0.60	0.176
HAND	4	10	13	905.2	9.39	7.48	1.81	0.216
HAND	4	10	14	53.8	5.30	2.23	0.64	0.186
HAND	4	10	26	25.6	3.19	2.34	0.81	0.296
HAND	4	10	27	23.7	3.54	1.93	0.54	0.207
HAND	4	10	33	38.5	3.74	2.78	0.50	0.155
HAND	4	10	40	39.4	3.80	2.20	0.82	0.284
HAND	4	10	46	77.9	5.08	3.46	1.28	0.305
HAND	4	10	67	45.1	5.94	1.72	0.50	0.156
HAND	4	10	79	99.2	6.87	2.49	0.84	0.203
HAND	4	10	81	93.7	4.37	3.90	0.68	0.165

Appendix 1. Raw data for Drill Study (Chapter 10): +20 mesh gold grains.

TYPE	AREA	SAMPLE	GRAIN	WEIGHT	LENGTH	WIDTH	THICK	CSF
	HOLE			(mg)	(mm)	(mm)	(mm)	
DRILL	1	5	3	15.9	2.52	1.66	0.52	0.254
DRILL	1	5	8	4.1	2.40	1.30	0.23	0.130
DRILL	1	5	9	103.0	4.43	3.02	1.02	0.279
DRILL	1	5	11	39.0	3.12	2.58	0.57	0.201
DRILL	1	5	12	24.6	2.60	2.48	0.52	0.205
DRILL	1	5	18	42.7	3.47	2.67	1.12	0.368
DRILL	1	5	19	26.4	1.92	1.80	0.70	0.377
DRILL	1	5	24	19.5	2.89	1.82	0.55	0.240
DRILL	1	5	28	27.7	2.97	2.58	0.48	0.173
DRILL	1	5	32	9.2	2.57	1.13	0.38	0.223
DRILL	1	7	26	91.4	4.43	3.00	0.72	0.198
DRILL	2	3	2	52.6	3.14	2.99	1.43	0.467
DRILL	2	3	4	9.5	2.70	1.48	0.33	0.165
DRILL	2	3	16	14.1	1.76	1.62	0.47	0.278
DRILL	2	3	17	22.0	2.48	2.23	0.44	0.187
DRILL	2	3	22	41.5	2.94	2.58	0.59	0.214
DRILL	2	3	25	45.9	3.76	3.00	1.03	0.307
DRILL	2	3	29	66.0	3.69	3.28	0.69	0.198
DRILL	2	3	30	8.3	1.40	1.36	0.61	0.442
DRILL	2	3	33	37.8	2.94	2.69	0.66	0.235
DRILL	4	4	7	4.4	2.08	1.31	0.24	0.145
DRILL	4	4	15	5.1	1.39	1.24	0.35	0.267
DRILL	4	4	21	5.6	1.99	1.35	0.35	0.214
DRILL	4	4	31	4.6	2.00	1.12	0.25	0.167
DRILL	4	6	1	14.9	2.44	1.72	0.46	0.225
DRILL	4	6	5	85.1	5.53	2.74	1.13	0.290
DRILL	4	6	10	5.9	1.90	1.62	0.33	0.188
DRILL	4	6	13	54.8	3.34	2.76	0.69	0.227
DRILL	4	6	14	16.7	2.60	1.88	0.60	0.271
DRILL	4	6	20	5.5	1.38	1.17	0.37	0.291
DRILL	4	6	23	9.0	1.79	1.55	0.64	0.384
DRILL	4	6	27	54.3	3.94	2.58	0.92	0.289
HAND	1	2	32	181.1	4.69	3.61	1.24	0.301
HAND	1	2	53	19.6	2.55	2.22	0.41	0.172
HAND	1	2	64	28.2	2.72	2.03	0.53	0.226
HAND	1	2	66	33.8	2.50	1.84	0.85	0.396
HAND	1	2	74	48.8	3.77	3.01	0.57	0.169
HAND	1	5	2	19.5	2.14	1.99	0.45	0.218
HAND	1	5	3	45.0	3.09	2.32	0.70	0.261
HAND	1	5	10	6.7	1.26	1.19	0.48	0.392
HAND	1	5	21	41.9	2.69	2.44	0.73	0.285
HAND	1	5	28	65.5	5.48	2.74	0.56	0.145

18.2. Appendix 2. Raw data, +20 mesh gold grains.

Appendix 2. Raw data, +20 mesh gold grains.

COUNT	GRAIN	SOURCE	WEIGHT (mg)	LENGTH (mm)	WIDTH (mm)	THICK (mm)	CSF	SPHER- ICITY	REGU- LARITY	PITTING	SURFACE AU (fine)	INTERIOR AU (fine)	AU DELTA (%)
1	34	A BENCH	20.1	2.33	1.90	0.48	0.228	4	1	3	1000	767	30
2	36	A BENCH	3.0	1.70	1.12	0.26	0.188	5	2	3	974	821	19
3	37	A BENCH	90.8	4.28	3.07	0.58	0.160	5	1	5	1000	--	--
4	39	A BENCH	19.5	2.01	1.81	0.52	0.273	4	1	3	968	683	42
5	40	A BENCH	18.8	2.41	2.50	0.38	0.155	5	1	5	948	742	28
6	42	A BENCH	27.2	2.90	2.70	0.48	0.172	5	1	4	990	775	28
7	45	A BENCH	35.3	3.87	2.16	0.38	0.131	5	1	3	978	803	22
8	19	A CHANNEL	8.8	1.42	0.82	0.18	0.167	5	3	1	969	776	25
9	21	A CHANNEL	18.4	2.94	1.95	0.37	0.155	5	4	3	966	--	--
10	22	A CHANNEL	13.5	3.01	1.56	0.38	0.175	5	3	3	969	706	37
11	24	A CHANNEL	31.2	4.16	1.93	0.49	0.173	5	1	3	990	726	36
12	28	A CHANNEL	8.7	2.48	1.26	0.37	0.209	5	2	3	979	733	34
13	29	A CHANNEL	7.3	2.49	1.24	0.30	0.171	2	3	3	996	834	19
14	30	A CHANNEL	8.5	2.00	1.22	0.34	0.218	4	3	4	968	751	29
15	91	B-PL	6.7	1.35	1.12	0.44	0.358	2	1	2	929	743	25
16	96	B-PL	41.5	4.14	1.98	0.50	0.175	4	2	3	968	826	17
17	99	B-PL	1.5	1.15	0.70	0.38	0.424	3	3	2	969	--	--
18	100	B-PL	34.3	3.26	2.42	0.48	0.171	5	1	5	969	732	32
19	101	B-PL	6.9	1.81	1.39	0.32	0.202	4	1	4	872	--	--
20	103	B-PL	49.1	3.32	2.93	0.56	0.180	4	1	3	948	--	--
21	104	B-PL	9.9	1.38	1.18	0.62	0.486	2	1	2	959	759	26
22	105	B-PL	17.2	2.93	1.79	0.46	0.201	4	2	3	979	752	30
23	79	TAMMANY	82.7	2.81	2.22	1.69	0.677	1	1	2	943	744	27
24	80	TAMMANY	48.1	3.23	2.63	0.65	0.223	4	2	3	892	744	20
25	81	TAMMANY	4.7	2.11	1.13	0.28	0.181	4	3	3	936	749	25
26	82	TAMMANY	6.0	1.49	1.18	0.39	0.294	3	3	4	958	738	30
27	85	TAMMANY	14.2	3.44	2.64	0.63	0.209	4	2	2	949	--	--

Appendix 2. Raw data, +20 mesh gold grains.

COUNT	GRAIN	SOURCE	WEIGHT (mg)	LENGTH (mm)	WIDTH (mm)	THICK (mm)	CSF	SPHER- ICITY	REGU- LARITY	PITTING	SURFACE AU (fine)	INTERIOR AU (fine)	AU DELTA (%)
28	86	TAMMANY	116.7	3.94	3.52	0.94	0.252	4	1	4	895	--	--
29	88	TAMMANY	29.7	2.84	2.42	0.68	0.259	5	4	2	939	734	28
30	116	LUCKY	7.0	1.96	1.47	0.48	0.283	3	5	2	949	838	13
31	118	LUCKY	11.1	1.64	1.24	0.85	0.594	2	2	2	912	--	--
32	121	LUCKY	12.3	1.84	1.00	0.93	0.686	3	2	3	967	771	25
33	123	LUCKY	120.6	3.81	2.88	1.40	0.423	3	4	3	957	--	--
34	124	LUCKY	35.5	2.44	2.00	1.81	0.819	1	4	2	966	735	31
35	1	WHITE	19.2	2.77	1.56	0.58	0.279	4	2	2	948	758	25
36	2	WHITE	2.7	1.22	0.96	0.42	0.388	3	5	2	819	--	--
37	5	WHITE	3.5	1.86	0.98	0.24	0.178	5	4	1	889	732	21
38	7	WHITE	15.3	4.66	0.94	0.30	0.143	5	2	3	955	739	29
39	10	WHITE	50.0	2.87	1.96	1.24	0.523	3	4	2	932	722	29
40	14	WHITE	11.2	2.55	1.01	0.56	0.349	5	5	2	862	735	17

-- Missing data

PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Black and white photographic prints (17" x 23") are available for an additional charge.

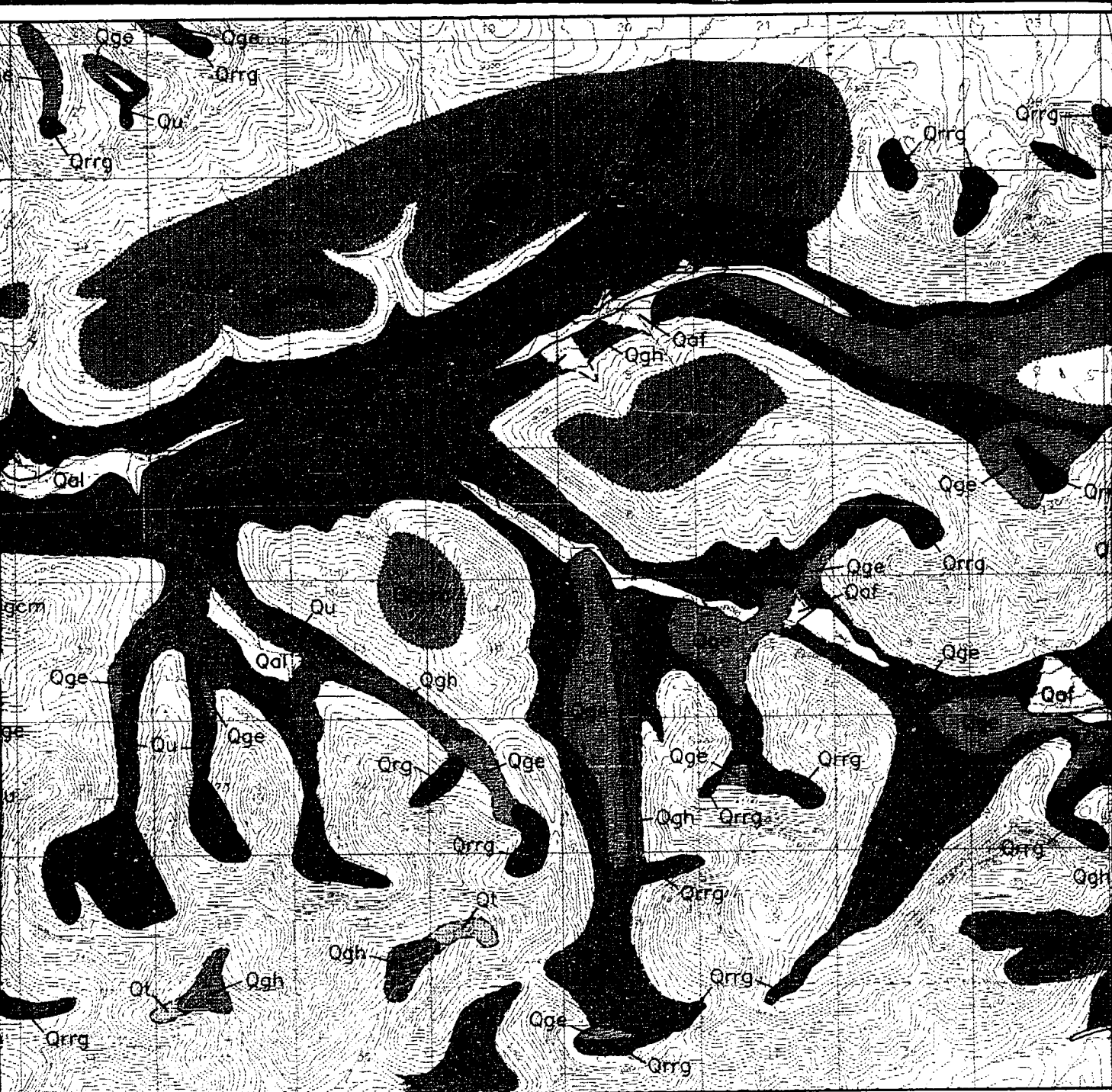
UMI



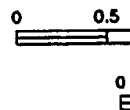
SURFICIAL

SIISITNA

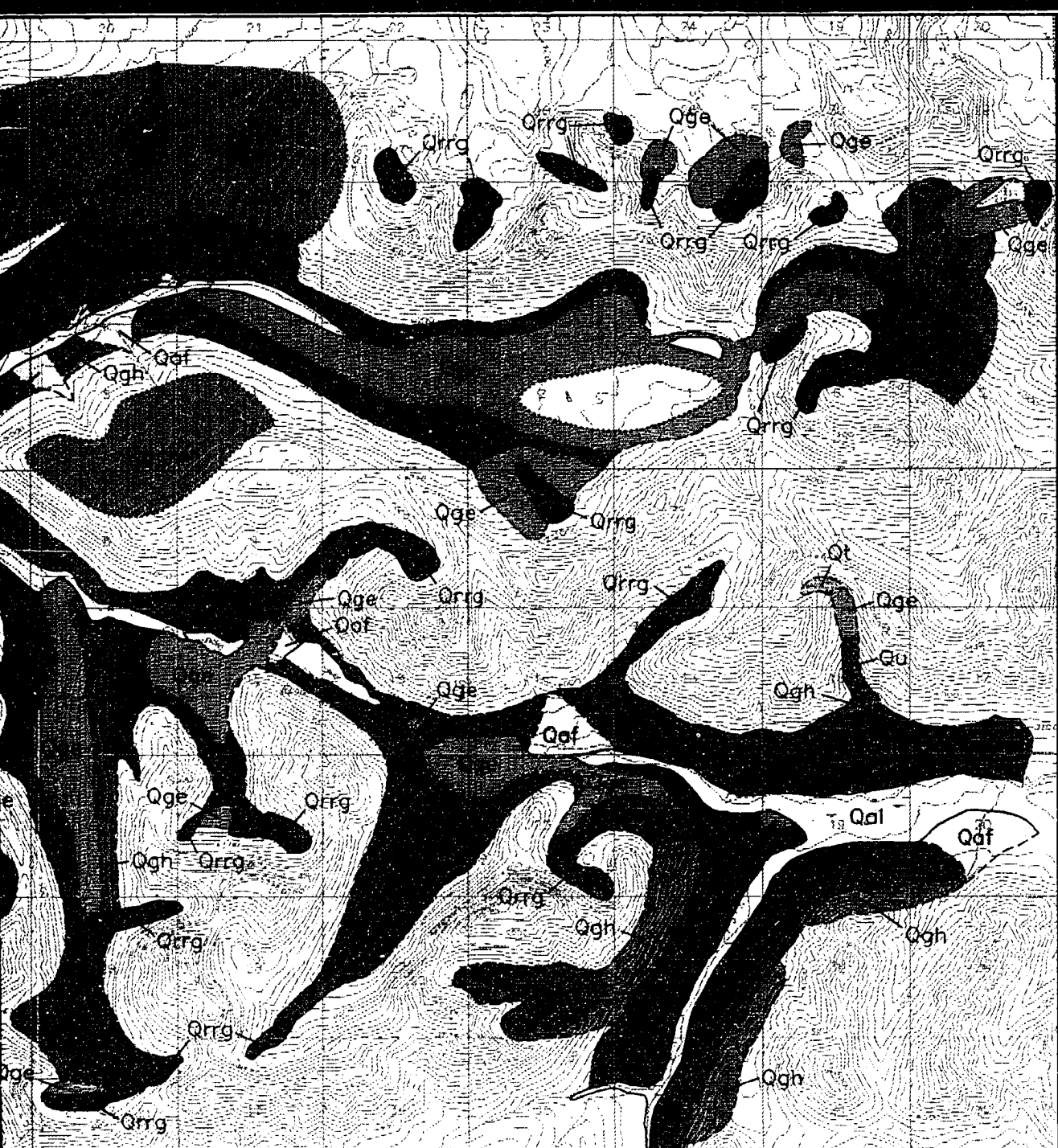
VALLEY CREEK



SURFICIAL GEOLOGY



VALDEZ CREEK
GLACIAL MAXIMUM



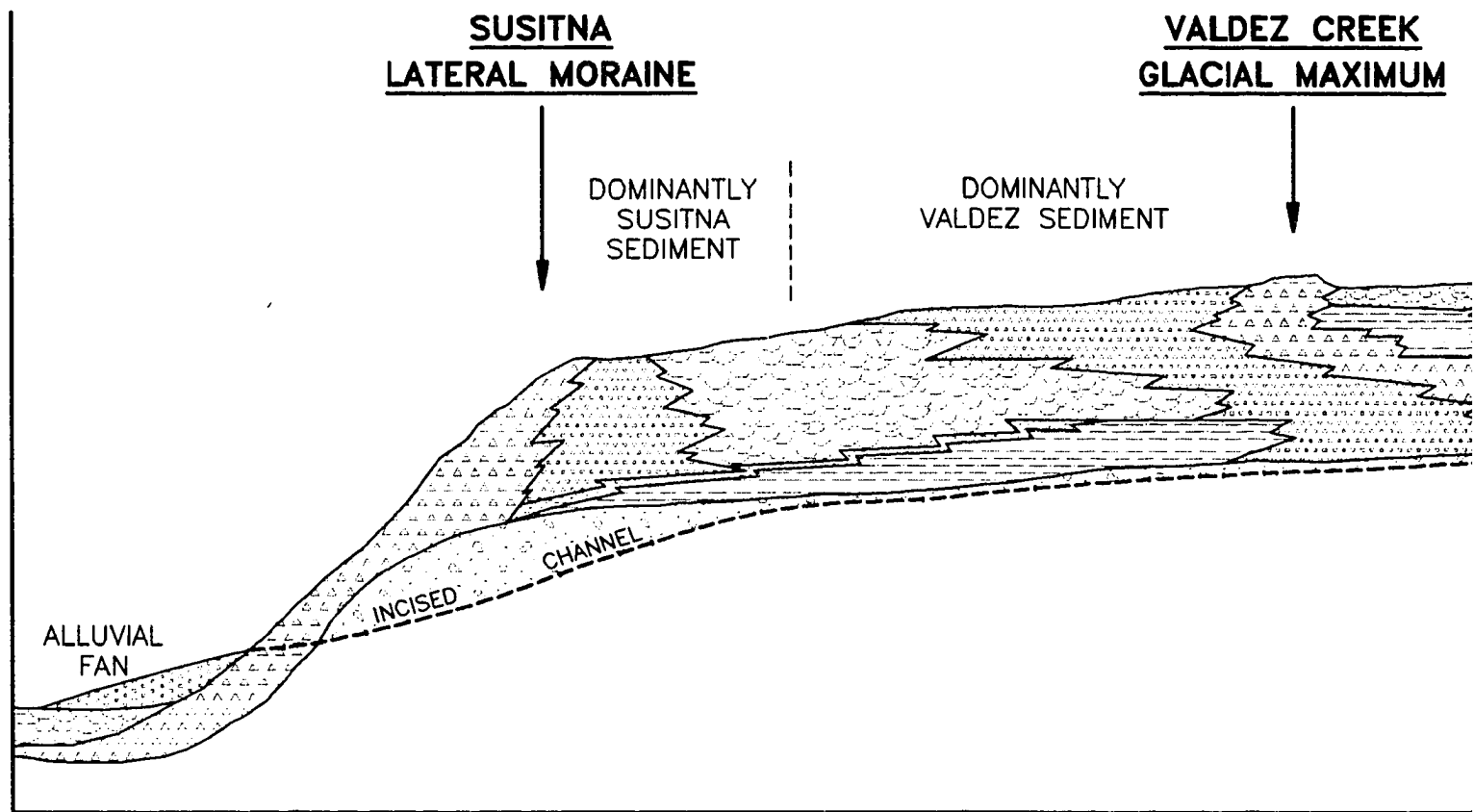
GEOLOGY

0 0.5 1 2 3 MILES

0 0.5 1 2 3 KILOMETERS

ROCK GLACIER





IDEALIZED LONG SECTION

EXPLANATION

UNDIFFERENTIATED SURFICIAL DEPOSITS

Undifferentiated - Generally areas of indistinct topography on lower portions of the valley sides where downslope movement has obscured the morphology; also areas of mixed till, talus, and alluvial fans.

NON-GLACIAL SURFICIAL DEPOSITS

Qal **Alluvium** - Deposits of moderately to well sorted and rounded sand to cobble deposits found principally in the broad Susitna River system of braided channels and along Valdez Creek. Locally includes lacustrine deposits.

SURFICIAL GEOLOGY

0 0.5 1

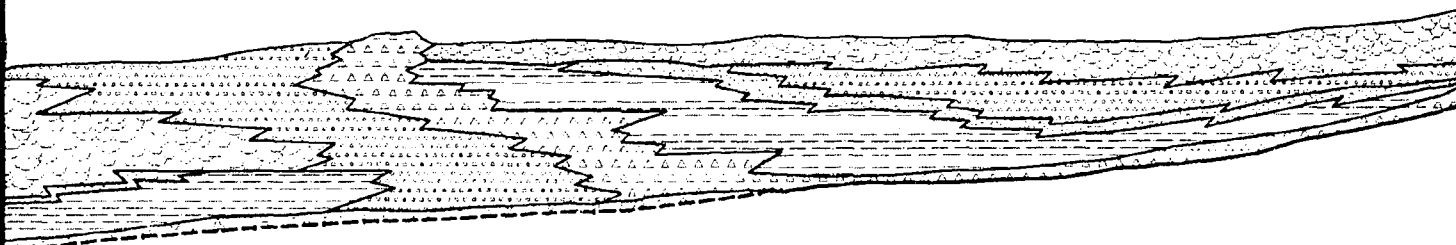
0 0.5

VALDEZ CREEK GLACIAL MAXIMUM



DOMINANTLY
VALDEZ SEDIMENT

VALDEZ CREEK SEDIMENT



BRAIDED STREAM



OUTWASH



DELTAIC

VALDEZ CREEK Simplified LONG SECTION OF VALDEZ CREEK

GLACIAL DEPOSITS AND ROCK GLACIERS (cont.)



Craig Creek — Represented by morainal remnant north of Valdez Creek and south of the pass into very low ridges with very subdued topography, 0.5 to 30 m between ridge crests. Exposed erratics diameter, and are half buried.



Clearwater Mt. — Extremely old glaciation represented by extensive erosional surface, found between 1200 in Valdez Creek. Surface topography is very subdued, very few surviving erratics, well developed solifluction associated marginal features recognized, scattered

topography on lower portions of obscured the morphology; also

and rounded sand to cobble
er system of braided channels
e deposits.

0 0.5 1 2 3 MILES

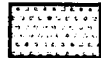
0 0.5 1 2 3 KILOMETERS

ROCK GLACIER

DIMENT



BRAIDED STREAM



OUTWASH



DELTAIC



LACUSTRINE



TILL



AURIFEROUS
FLUVIAL GRAVEL

VALDEZ CREEK


GLACIAL SURFACES AND ROCK GLACIERS (cont.)

Valdez Creek - Represented by morainal remnants found on the high level surface of Valdez Creek and south of the pass into Craig Creek. The moraines form ridges with very subdued topography, 0.5 to 1.0 m deep swales and 15 m between ridge crests. Exposed erratics are rare, approximately 1 m in diameter and are half buried.


Older Mt. - Extremely old glaciation represented by remnants of a regionally extensive erosional surface, found between 1200 m (4000 ft) and 1500 m (5000 ft) on Valdez Creek. Surface topography is very subdued with well developed soil and surviving erratics, well developed solifluction lobes on steeper slopes, no distinct morainal features recognized, scattered erratics found on affected ridges.


EXPLANATION


UNDIFFERENTIATED SURFICIAL DEPOSITS

 **Undifferentiated** - Generally areas of indistinct topography on lower portions of the valley sides where downslope movement has obscured the morphology; also areas of mixed till, talus, and alluvial fans.


NON-GLACIAL SURFICIAL DEPOSITS

 **Alluvium** - Deposits of moderately to well sorted and rounded sand to cobble deposits found principally in the broad Susitna River system of braided channels and along Valdez Creek. Locally includes lacustrine deposits.


 **Alluvial fan** - Fan shaped deposits of alluvium found at the foot of many drainages in the map area; often covers alluvium or till. The Valdez Creek fan is largely redeposited placer tailings from historical mining activity.


 **Talus** - Generally interconnecting cones or mantles of rock fall debris at slope break; no glacial morphology.

GLACIAL DEPOSITS AND ROCK GLACIERS

 **Rock glacier** - Found in many high cirques; pristine morphology, no soil development, no lichen growth on over-steepened, active slopes.

 **Relict rock glacier** - Found in many high cirques; pristine morphology and no soil development.

 **Eldorado Creek** - Found in Eldorado Creek, upper Valdez Creek and Grogg Creek. Very well preserved morphology, thin soil development, and sparse vegetation. Considerably better preserved morainal morphology with much less soil development and vegetative cover than Hatchet Lake deposits.

 **Hatchet Lake** - Forms broad lateral moraines along the Susitna River with numerous small and large lakes and closed depressions, generally heavily vegetated, numerous erratics of all sizes are well exposed on ridges. Represented by recessional and terminal moraine in the Valdez Creek drainage; very little knob and kettle topography which is well preserved when present, soil profiles are variable but generally about 15 cm of moderate to dark brown to red-brown A horizon, clasts exhibit minor weathering only.

QUATERNARY GEOLOGY OF

By Stev

IDEALIZED LONG SECTION OF VALDEZ CREEK

distinct topography on lower portions of
has obscured the morphology; also

sorted and rounded sand to cobble
na River system of braided channels
ustrine deposits.

uvium found at the foot of many
uvium or till. The Valdez Creek fan is
rical mining activity.

mantles of rock fall debris at slope


s; pristine morphology, no soil develop-
active slopes.


cirques; pristine morphology and no

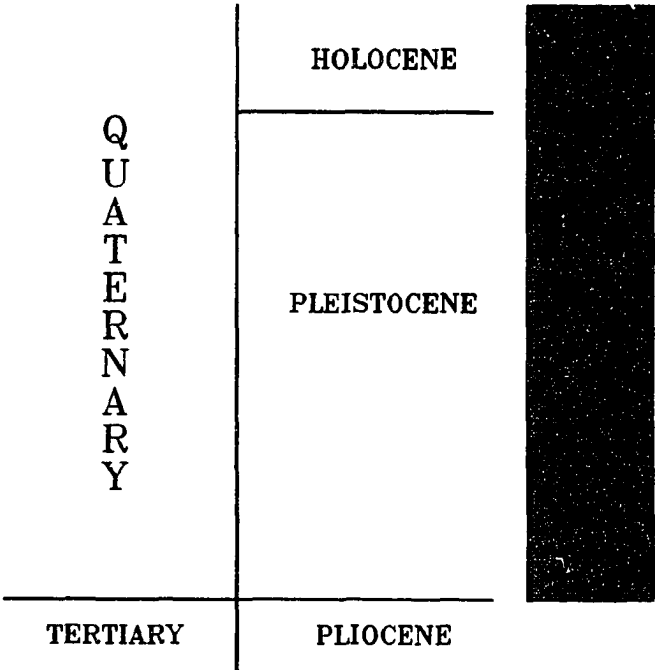
upper Valdez Creek and Grogg Creek.
velopment, and sparse vegetation.
hology with much less soil development
osits.

hes along the Susitna River with
depressions, generally heavily vegetated,
sed on ridges. Represented by reces-
reek drainage; very little knob and
en present, soil profiles are variable but
brown to red-brown A horizon, clasts

GLACIAL DEPOSITS AND ROCK GLACIERS (cont.)

 **Craig Creek** - Represented by morainal r
north of Valdez Creek and south of the pa
very low ridges with very subdued topograp
to 30 m between ridge crests. Exposed e
diameter, and are half buried.

 **Clearwater Mt.** - Extremely old glaciation
extensive erosional surface, found between
in Valdez Creek. Surface topography is ve
very few surviving erratics, well developed s
associated morainal features recognized, sc
tops. Extent of erosional surface is shown



Y GEOLOGY OF THE VALDEZ CREEK

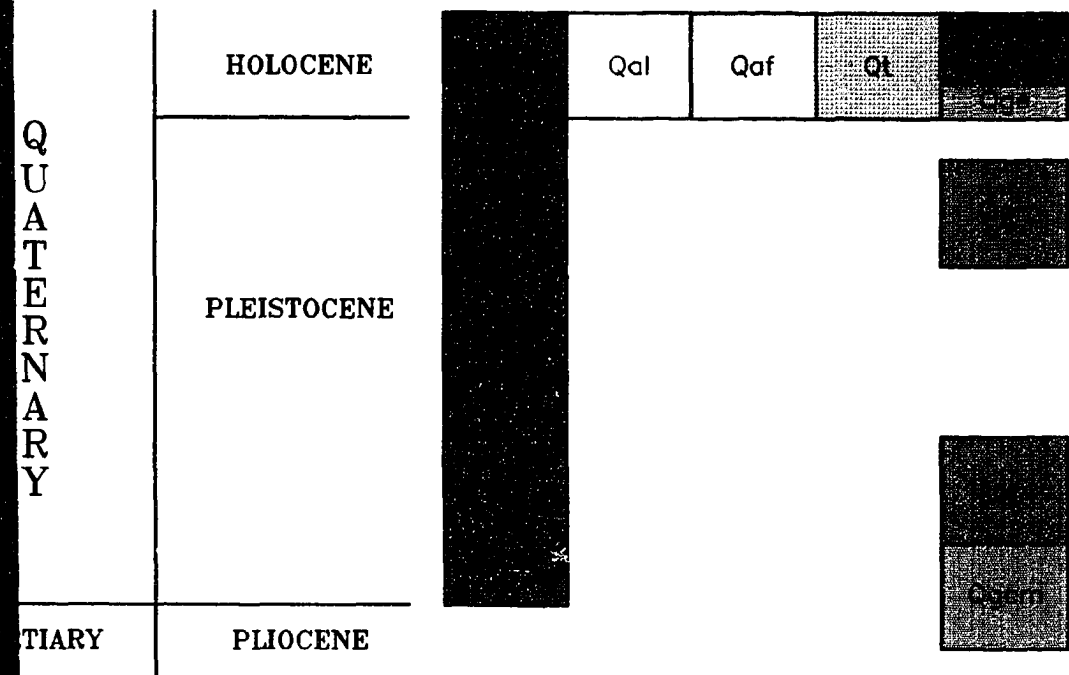
By Steve Teller

VALDEZ CREEK

DEPOSITS AND ROCK GLACIERS (cont.)

g Creek - Represented by morainal remnants found on the high level surface of Valdez Creek and south of the pass into Craig Creek. The moraines form low ridges with very subdued topography, 0.5 to 1.0 m deep swales and 15 to 30 m between ridge crests. Exposed erratics are rare, approximately 1 m in diameter, and are half buried.

Arwater Mt. - Extremely old glaciation represented by remnants of a regionally extensive erosional surface, found between 1200 m (4000 ft) and 1500 m (5000 ft) on Valdez Creek. Surface topography is very subdued with well developed soil and few surviving erratics, well developed solifluction lobes on steeper slopes, no associated morainal features recognized, scattered erratics found on affected ridge. Extent of erosional surface is shown.



VALDEZ CREEK AREA